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THE NEW FARMING

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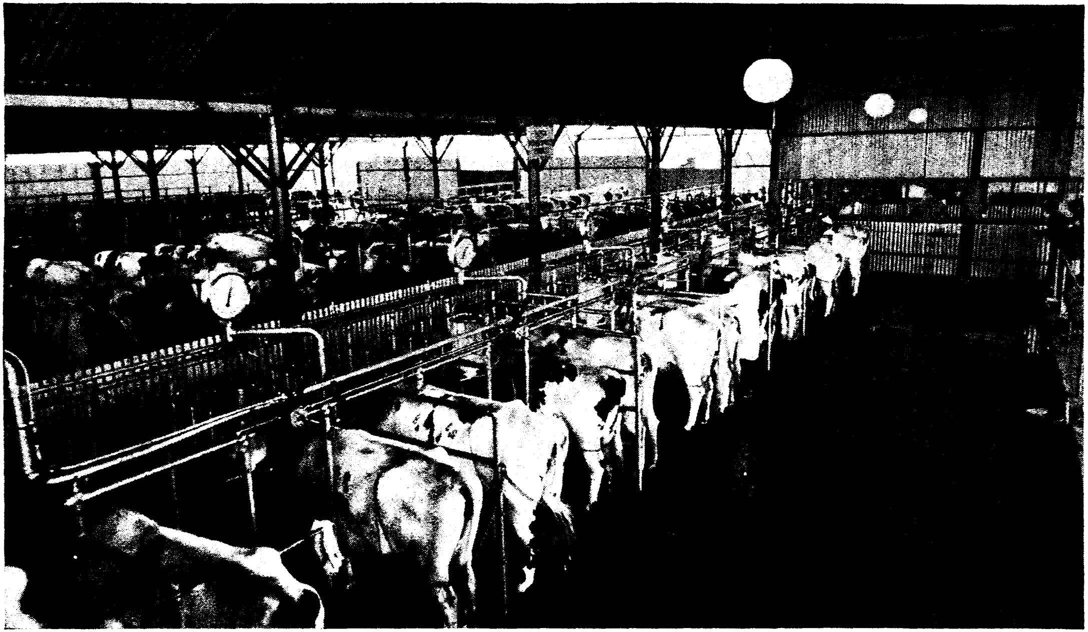

A modern cow-house equipped for machine milking and automatic weight recording of the milk.

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THE NEW FARMING

by

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TO
MY MOTHER AND FATHER

PREFACE

This little book has been written in the hope of interesting the intelligent layman in the scientific side of agriculture, and of helping to dispel the idea that farming is an occupation suited only to the dull-witted members of a community. So much is written nowadays about the application of scientific methods to commercial undertakings that it is very desirable to restate the fact that agriculture makes as full a use of science as any industry in the country. Some of the ways in which science is being applied to farming problems are described in the following pages, and additional sources of information are indicated at the end of each chapter.

I take this opportunity of thanking numerous colleagues for their criticisms and suggestions during the preparation of the manuscript, also those who have kindly placed photographic illustrations at my

D. H. R

HARPER ADAMS AGRICULTURAL COLLEGE,
NEWPORT, SHROPSHIRE,
May 1938.

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THE NEW FARMING

CHAPTER I

INTRODUCTION

FARMING is not, and never will be, an exact science. Farming is an art, and to make a living a farmer must be both an artist and a business man. From a strictly materialistic point of view, business ability, not skill in cultivation nor scientific knowledge, is the most important single attribute to success in farming. Fortunately, most farmers are not narrowly materialistic, and whilst desiring to make a comfortable living for themselves and their families they also wish to do their duty by the land, to maintain it in good heart, and not tear out its goodness for immediate profit.

The intense competition brought about by modern conditions of life have made impossible the leisurely methods of farming which were practised during the nineteenth century. Diligence on the part of the farmer himself, together with plentiful applications of " muck " and liberal supplies of oil-cake, are no longer sufficient to ensure success. Some knowledge of developments in modern science is essential if the farmer is to make the best use of the materials at his disposal. He must have a smattering of general scientific knowledge to enable tural mind been so receptive to scientific teaching, provided that it can be grafted on to the business of farming. In the following chapters some account is given of the numerous ways in which science is at this moment helping the farmer in his business. The arrangement of the material is obviously open to criticism because of the complexity of the problems that the agricultural scientist is called upon to solve. Soil fertility, for example, is not a matter entirely for the chemist. It demands the co-operation of at least the chemist, biologist, plant breeder, and engineer. Some overlapping is consequently unavoidable. The chief concern of this book is to indicate the application of science to everyday farming, not to give a résumé of current agricultural research. For a more detailed account of the technicalities involved the reader is referred to the publications mentioned at the end of each chapter.

Collateral Reading

The most important weekly papers entirely devoted to agricultural matters are *The Farmer and Stock-Breeder* and *The Farmer's Weekly*, both published in London. Most of the important daily papers in London and the provinces have an agricultural correspondent. *The Field* and *Country Life*, amongst weekly magazines, also devote considerable space to farming topics. The most important monthly Journal is *The Journal of the Ministry of Agriculture*, which is an official publication. *The Estate Magazine* also appears monthly. *The Scottish Journal of Agriculture* is a quarterly publication of the Scottish Department of Agriculture. *The Welsh Journal of Agriculture* is [illegible]l annually. *Agricultural Progress* appears three times a year; it is the Journal of the Agricultural Education Association. The Royal Agricultural Society issues a Journal annually: with it is included "The Farmer's Guide to Agricultural Research," which is a summary of the chief investigations under progress during the preceding twelve months.

INTRODUCTION

Technical papers on agricultural research are published in numerous journals. The chief of these are *The Journal of Agricultural Science*, *The Annals of Applied Biology*, *Soil Science*, *The Journal of Dairy Research*. *The Journal of Agricultural Research*, an American publication, is also useful.

The quantity of published research throughout the world on agricultural matters is so great that it is impossible for any one person to keep in touch with all that affects even one particular aspect. To assist scientific workers numerous summaries are published at intervals. The most comprehensive one in English is *The Experiment Station Record*, published in the U.S.A. This deals with all phases of agricultural science, and is published twelve times a year. Other sectional reviews are *Herbage Abstracts*, *The Review of Applied Entomology*, *The Review of Applied Mycology*.

CHAPTER II

SOIL AND FERTILITY

PLANTS, which are absolutely essential to animal life, obtain their nourishment partly from the soil and partly from the air. From the carbon dioxide of the air plants obtain, through the medium of their green colouring matter called chlorophyll, the carbon which is so essential to the formation of " organic " substances such as starch, sugar, protein, and oil. From the soil plants obtain their water, their nitrogen, and mineral substances such as calcium, phosphorus, potassium, iron, etc. The atmosphere cannot be controlled by the farmer, though it has been demonstrated that increased growth of plants can be obtained in special greenhouses where the proportion of carbon dioxide is artificially increased. But the soil can to some extent be controlled, or if not controlled can be coaxed into a condition favourable to the growth of plants—hence a great deal of scientific investigation has been directed towards the soil and its bearing upon fertility.

Modern research goes to show that the soil has a much more complicated structure than was thought to be the case at the beginning of the present century. For our present purpose we may consider that soil consists of mineral matter, organic matter, soil water, soil air, soil animals, and small soil plants. The fertility of a soil depends upon the interaction of all these components, hence it is obvious that the problem is a very complicated one.

Science is seeking to aid the farmer by tackling the problem in four main directions : classification, study of the physical characters, study of the chemical characters, and study of the biological factors in the soil. Of course, it is impossible to separate these factors in actual practice, but individual study is essential if accurate information is to be obtained in the end.

The classification of soils has undergone great developments since 1920, being stimulated by work carried out in Russia. Previously, much stress had been laid upon the relation of a soil to its geological formation, and very sweeping statements were made and deductions drawn from the evidence of geological surveys. Soil chemists of to-day do not deny that the underlying rock (geological formation) has a very great influence on soils, but they are now more inclined to study in detail the peculiarities of the soils themselves rather than base their conclusions upon the evidence of geologists. They demand soil surveys as distinct from geological surveys.

Soil surveys are not new. The early soil workers concentrated upon the first foot or so of the soil, and based their work largely upon its physical and chemical nature. They dealt with it in layers nine inches thick, starting from the surface. Numerous methods of analysis were in use, but the results obtained by workers in one area could not always be correlated with those obtained in other surveys. Modern soil surveys are being conducted upon more or less standard lines throughout the country, so that the published data can be understood and interpreted by workers in different areas. There is, too, a tendency to pay more attention to what is called the "soil profile," that is, the different layers of soil from the surface down to the parent rock. Samples of these different layers are analysed in the laboratory to obtain information about their physical and chemical composition, and the soils are then classified into series which can be indicated upon soil maps. These soil maps also include details of other matters of farming importance, so that a skilled man, looking at these maps, can gain a very good idea of the capabilities of any particular soil. Soil surveys are already proving very useful to those scientists whose business it is to advise farmers upon cropping and manuring, and there is no doubt that they will prove of extreme value as the mapped areas extend.

Surveys of this sort depend upon field examination and the analysis of soils, both physical and chemical. In physical analysis the size of the soil particles is of great importance, and so is the amount of organic matter. The organic matter, frequently and loosely called humus, is made up of rotting vegetable and animal matter, and since it is mainly that part of the soil destroyed by burning, it is determined by igniting the soil. The mineral part of the soil is separated out into various " fractions " according to the size of its particles. The common fractions are :

Coarse sand,	having particles with a diameter of	2 – .2 mm.
Fine sand,	,, ,, ,, ,,	.2 – .02 mm.
Silt,	,, ,, ,, ,,	.02 – .002 mm.
Clay,	,, ,, ,, ,,	less than .002 mm.

It has been found that the texture and behaviour of a soil depend very largely upon the proportions of " clay " and silt relative to the amount of sand and modified by the organic matter present. Clay particles are very tiny, and expose a tremendous area of surface : a cubic foot of clay may have an internal surface of 100,000 square feet. The clay and the humus together form what is called the colloidal complex. It is not possible here to describe at all adequately what is meant by a colloid ; it must suffice to say that a colloid consists of materials with remarkable powers of absorption and retention. A well-drained sandy soil is usually deficient in this colloidal matter, so that it will not retain the soil water, and soluble fertilizing material washes out very readily. In some clay soils, on the other hand, there may be an excess of this material, with the result that too much water is retained and the amount of air present in the soil becomes insufficient for healthy root growth.

The discovery of the colloidal behaviour of soils is greatly influencing modern research, but the investigations are extremely technical in character. It has been found that the amount of calcium in a soil exercises a great influence upon the soil colloids. It causes the tiny colloid particles to unite or coagulate into larger particles—the process is called flocculation. In a clay soil this flocculation is of considerable benefit to the texture of the soil, and it partly explains why the application of lime (either as calcium oxide or calcium carbonate) is so useful.

The mechanical analysis of a soil, that is, an investigation into the size of the soil particles, can by itself give much information to the soil chemist. For example, a soil containing 30 per cent. each of silt and clay would be a very tenacious one, suitable for growing field beans ; a soil with 30 per cent. silt and 20 per cent. clay would be likely to grow good wheat. A good barley soil would probably have 25 per cent. of fine sand and about 40 per cent. of silt, whilst a soil with 50 per cent. coarse sand and about 15 per cent. each of fine sand and silt would most likely prove profitable under market garden cropping and sugar beet.

But mechanical analysis alone does not tell us everything; some indication of the chemical nature of the soil is also desirable. Experience shows that in the majority of soils only four elements are likely to be deficient from the point of view of plant nutrition—namely, calcium, nitrogen, phosphorus, and potassium.

The total amount of these elements in a soil is very large, but only a proportion is at any given time capable of being absorbed by the roots of plants. This fact was not properly realized by the early analysts, whose conclusions and recommendations were often so much at variance with the experience of farmers that for a time the chemical analysis of soils was regarded with distrust. But towards the end of last century it was found that a very good idea as to the "availability" of the mineral elements, and especially of phosphorus and potassium, could be obtained by shaking up a soil with a 1 per cent. solution of citric acid, and analysing the liquid under standard conditions.

A soil with less than .01 per cent. of available phosphoric acid can be regarded as deficient in phosphorus, and likely to benefit from a good dressing of phosphatic manures. If the available potash is below .01 per cent. the same can be said of the potassium. It must be emphasized, however, that these figures require interpretation if a reasonably accurate idea of the state of things is to be arrived at, and sound advice given to the farmer. The experience of the soil chemist is here in-valuable if mistakes are to be avoided. By themselves the figures mean very little and may be very misleading; but coupled up with local knowledge they can be extremely useful.

In order to obtain more reliable information about the manurial requirement of soils new methods have been devised. One method which has become very popular amongst farmers in East Prussia, though it has not been used to any extent in this country, is called the Mitscherlich method, after its inventor. Without going into unnecessary detail, it may be said that the method is based upon the yield of dry matter produced by oat plants growing in pots of the soil under test, under different manurial treatments. For each soil under test 16 pots are required, divided into 4 series. One series is given a fertilizer containing nitrogen, phosphoric acid, and potash. In the other series, one constituent in turn is left out of the manure. Great care is taken to equalize the moisture in each pot, and at harvest the dry matter in the straw and grain is determined. From the result it is possible to calculate how much available phosphoric acid and potash was originally present in the soil; and from these figures it is possible to advise the farmer how to manure his fields for each crop. The method takes the whole of a growing season, and is therefore slow; it is also expensive, because of the number of separate pots which have to be looked after. Criticisms have also been made of the theories upon which the method is based, but as already mentioned, farmers in parts of Germany have been impressed with the advice given them by exponents of the Mitscherlich method, and hundreds of samples of soil are tested yearly.

A much more rapid method is that devised by Neubauer, based upon the rapid absorption of soluble plant foods by young seedlings. It is concerned with the phosphoric acid and potash requirements only, and because of the ease with which rye absorbs these constituents a variety of this cereal having a good germination capacity is used. The soil sent in by a farmer is air-dried and sifted through a 2 mm. sieve; a given quantity is placed in a cylindrical glass dish of standard pattern and mixed with half its weight of pure quartz sand. A definite amount of fine, moist sand is put on top, and by means of a special marker 100 seeds of rye are planted therein. The seeds are disinfected before planting. The pots are weighed and kept at a temperature of 20° C., and the amount of moisture is carefully standardized. Seventeen days from the time of planting, the complete seedlings, roots as well as shoots, are burnt, and the ashes carefully analysed to find out how much phosphoric acid and potash they contain. The amount of these substances in the original seed is estimated by growing other seedlings in pure sand. By subtracting the amounts of phosphoric acid and potash found in the "blank," or control plants, from those present in the other seedlings, the quantities of the fertilizing constituents extracted from the soil can be obtained. By comparing these figures with the amounts of food known to be required by any particular crop, the soil deficiency can be determined. It is then a simple matter to advise the farmer to apply so many hundredweights of phosphatic and potassic fertilizer. No estimation of the nitrogen deficiency is made, because it is assumed that the soil will in any case need nitrogen—a conclusion confirmed by practice and experiment. The Neubauer method has been used for several years by a sugar beet

Examining a soil in the field for acidity.

Soil has been withdrawn to a depth of about a foot with the auger, and is being tested colorimetrically for lime deficiency.

(*Photo, D. H. Robinson.*)

company in this country to advise their growers as to the manurial requirements of their sugar beet soils.

Both the Mitscherlich and Neubauer methods require much careful supervision and neither is suitable for the ordinary laboratory. A simpler method makes use of a soil micro-organism called *Azotobacter*. The soil to be tested is mixed up into a paste with starch and china clay and divided into various portions; phosphate is added to some portions, potash to others. The pastes are put into an incubator kept at a temperature of 30° for 24–48 hours. The organism forms small specks or colonies. If the soil contains sufficient phosphate and potash there is no difference between the number and size of the colonies in the differently treated samples. If, however, the soil is deficient in potash, the dish receiving extra potash will show a more vigorous growth; a deficiency in phosphate is indicated in a similar manner. A scale has been devised whereby it is possible, on broad lines, to correlate the growth of the colonies with the actual requirements of a soil.

Yet another method depends upon the growth of a mould, or fungus, called *Aspergillus*, in a culture solution to which soil has been added. By varying the culture solution, and weighing the felt-like mass of the fungus which forms at the end of several days' incubation, it is possible to get an idea as to the requirements of the soil in potash and phosphoric acid. A more rapid method still is to extract the soil with a mixture of acetic acid and sodium acetate. By adding to this solution certain chemicals a blue colour is produced; by comparing the intensity of this blue with colours set out on a chart, it is claimed that a fairly reliable estimate can be made of the available phosphoric acid in the soil. The available potash can be estimated by a simple precipitation method, in which the quantity of sediment thrown down is compared with a scale.

One of the most serious problems in modern farming is that of soil acidity. An acid, or sour, soil will not grow successful crops, and it is an unfortunate fact that many thousands of acres in this country are acid to a greater or less extent: the seriousness of the position from a national point of view has been recognized by the Government, who, in their Land Fertility Scheme, are subsidizing the application of lime to farm soils in order to overcome this acidity and so increase fertility. The scientist is here called upon to do two things: first, to recognize the degree of acidity in any particular soil, and second, to recommend a dressing of lime which will be sufficient to overcome the acidity without being unnecessarily extravagant. To apply too little lime is useless; to apply too much is wasteful, because lime soon disappears from the soil and its effect is lost.

Years ago farmers were recommended to shake up some of their soil with a small quantity of hydrochloric acid (spirits of salt) in a tumbler, and listen for a fizzing sound or watch out for bubbles. If these were not forthcoming the soil was considered to be in need of lime. This very crude test is now regarded with the greatest disfavour, for it is based upon a misapprehension of the function of lime in a soil. Nowadays the intensity of acidity in a soil is measured by the hydrogen-ion concentration, and is expressed by the pH number. On the hydrogen-ion concentration scale a neutral soil would be represented by the number pH7, a strongly acid soil by pH4.5, a slightly acid soil by pH6.0–6.5. A soil with a pH7.1 would be alkaline. In other words, the lower the pH figure, the greater the acidity. British soils range from pH3–pH8. Under farming conditions it is commonly agreed that any soil having a pH figure above 6.5 can be regarded as non-acid. It does not pay to raise the hydrogen-ion concentration above this figure and attain absolute neutrality, or even alkalinity.

For accurate work the hydrogen-ion concentration is determined by an electrical method, but it is possible to obtain an approximate idea by the use of special coloured solutions. One of the most popular " soil indicators " is a solution of bromo-thymol-blue and methyl red. A few drops of this mixed up with a small quantity of acid soil will give a reddish or orange colour ; if the soil is non-acid, the solution turns blue or bluish-green. Use of the soil indicator gives a rough idea as to the nature of the soil, but it is unwise to regard it as anything more.

Electrically determined, however, the hydrogen-ion concentration provides valuable information. Experience shows that as a rule alsike clover, red clover, sugar beet, mangolds, and barley will not succeed on a soil with a pH of 5.3 or under. On the other hand, oats and potatoes will tolerate an acidity of as much as pH4.2. Obviously it is possible to suggest variations in cropping based upon the hydrogen-ion concentration of a soil.

Recent investigations have shown that the colloidal matter previously referred to is the seat of the reaction changes in a soil—that is, it causes acidity or alkalinity. The particles have loosely attached to them both acidic and basic material ; a predominance of the former causes an acid soil, of the latter a non-acid soil. The only basic material of any importance in this connection in English soils is calcium, which can be supplied to soil in the form of lime. The pH figure does not tell an analyst how much lime must be added to a soil to counteract any given acidity, so special methods have to be used.

One widely used method of determining "lime requirement" is the Hutchinson and McLennan method. Here the soil, when treated with calcium bicarbonate, absorbs some of the calcium; the amount absorbed gives a measure of the amount of lime (calcium oxide or calcium carbonate) needed to bring about non-acid conditions. There are also titration and other methods; by using these, soil chemists are able to gauge fairly accurately the most economical rate at which to apply lime on any particular soil. The estimation of lime requirement is not in any sense a mere routine process, but must be made in the light of field experience. In all work on soils designed to assist the farmer, practical acquaintance with the soils as they are on farms is just as important as laboratory analyses.

Lime is indeed one of the most essential substances that can be applied to a soil. This is not in itself a new discovery, because many of the virtues of the substance were recognized a century or two ago, and our forefathers were in the habit of spreading over their land large amounts of calcium in the form of lime, chalk, marl, and certain types of sea sand. Modern science has, however, been able to explain many of the reasons why lime is so essential, and to suggest new uses, as, for example, its employment in the rotting down of the mat of vegetation which prevents the proper functioning of much acid grassland.

There are certain cases where the liming of land is not desirable, such as peaty soils intended for an oat crop. Oats in some parts of the country suffer from a complaint called "grey speck," in which the leaves become streaked with greyish white areas; the plants are unhealthy and stunted, and yield very badly. It has been found that this complaint is a "deficiency" disease, due to lack of available manganese in the soil; it is accentuated—in soils of this silty, peaty nature—by liming. It is found on other soils too, and may be corrected by applying small quantities of manganese to the soil. Manganese sulphate at the rate of one hundredweight per acre has also been found effective. Basic slag usually contains enough manganese to right matters if about 4–5 cwts. are applied per acre.

The most striking example of a deficiency disease in a farm crop experienced in this country is the "heart rot" of sugar beet. In this complaint the centre part or crown of the beet plant turns black and rots away; the leaves die, and of course the yield per acre is much reduced. For a long time it was thought that the disease was caused by a fungus or bacterium, but after lengthy investigations it became apparent that lack of the element boron is responsible. Only minute traces of boron are required by the beet plant, but in some soils there is not sufficient available for the needs of the plant. The application of less than 30 lb. per acre of borax is sufficient to make healthy growth possible. Remembering that an acre of land occupies a square with sides approximately 70 yards long, it will be appreciated how small a dressing of borax this is, and how small may be the margin between success and failure in modern farming.

Science has been of the utmost value to the farmer in the case of nitrogenous fertilizers. It will be recalled that not so very long ago, about the end of last century, it was thought that the world would soon be faced with a shortage of nitrogen, and that food production would in consequence suffer a severe decline. The first substance rich in nitrogen to be used as manure was nitrate of soda, which was first imported from Chile in 1831. This material contains about 15½ per cent. of nitrogen, and it soon became very popular. Guano, the dried excrement of sea birds, deposited in rainless areas along the coasts of Peru, contains about 8 per cent. nitrogen, plus a certain amount of phosphoric acid and potash; it was first imported into England in 1840. For a long time farmers had no other choice of nitrogenous fertilizer; then, with the development of the gas industry, considerable amounts of sulphate of ammonia became available. This substance is formed by neutralizing with sulphuric acid the ammonia driven off during the distillation of coal to form coal gas. But even the large supplies of this manure failed to satisfy the world demands for nitrogen.

The idea of extracting nitrogen from the air for commercial and agricultural purposes has long fascinated the chemist. The atmosphere is composed of approximately four parts of nitrogen to one part of oxygen, yet, with only one or two exceptions, plants are unable to make use of this atmospheric nitrogen for growth. A successful method of nitrogen extraction from the air would obviously do away with the bogy of a nitrogen shortage, and make possible a much more intensive system of crop fertilization. It was not until 1904 that this dream was first realized. In that year nitrogen from the air was caused to combine with calcium carbide in an electric furnace to form calcium cyanamide, a greyish powder containing about 20 per cent. nitrogen. Calcium cyanamide, also called nitrolim, is used both as a nitrogenous fertilizer and as a destroyer of certain weeds.

After the war, a big expansion took place in connection with a process invented by Haber in Germany. Hydrogen derived from water gas is caused to combine with atmospheric nitrogen to form ammonia. A pressure of 200 atmospheres and a temperature of 500° C. are required, as well as the presence of certain chemicals which act as catalysts. The ammonia is caused to react with gypsum (calcium sulphate) to form sulphate of ammonia. During the last few years the production of this "synthetic" sulphate of ammonia has increased enormously. During 1936–37 the world production of *pure* nitrogen in the form of synthetic sulphate of ammonia was 654,000 metric tons, compared with 407,000 metric tons of sulphate of ammonia from gasworks. The total world production of pure nitrogen in all other forms during this period was 1,553,000 metric tons, so that the importance of the synthetic product, unknown twenty years ago, needs no emphasis. In the British Isles 226,000 tons of sulphate of ammonia were used on farms during 1936–37.

During the Haber process of extracting nitrogen from the air, considerable quantities of calcium carbonate (chalk or lime) are thrown out as a waste product. During the early years of the development of the process this lime was sold cheaply in order to dispose of it, but now it is used at the factory in the manufacture of nitro-chalk. This is a mixture of ammonium nitrate and calcium carbonate, and it is greatly liked by farmers for application to land where sulphate of ammonia is not altogether desirable. Sulphate of ammonia tends to make a soil acid, whereas nitro-chalk contains much free lime.

Another scientific development in the fertilizer industry which is of use to farmers is the sending out of nitrogenous and compound fertilizers in a granular form. Powders and crystalline substances are very liable to become lumpy or to form hard cakes when stored in bags, and this means that distribution by a manure drill is made difficult and uneven. By dropping the material down a tower through an uprising current of warm air, a granular form can be given to certain fertilizers. These granular substances store much better and do not go lumpy or sticky.

The provision of plentiful supplies of phosphatic fertilizers has had a profound influence upon modern agriculture and agricultural research. Previous to the work of Liebig, the great German chemist, in the early part of last century, bones were almost the only source of phosphoric acid available to farmers. They were finely ground, but the supply was limited and the manure was slow acting. By treating bones with sulphuric acid Liebig made "superphosphate," a much more rapidly acting fertilizer. Lawes, in 1842, took out a patent for the manufacture of superphosphate, using mineral, or rock, phosphate instead of bones. This phosphatic manure proved extremely useful and did much to improve the fertility of light lands specially suited to growing turnips. Lawes made a big fortune, and founded the first agricultural experiment station in the world at Rothamsted, near Harpenden in Hertfordshire. More recently, since about 1920, the phosphatic rocks themselves have been used, without the treatment with sulphuric acid. The idea of using the acid is to change the insoluble phosphate into a soluble form available to plants. It has been discovered that by grinding the rock to a very fine powder the phosphate will dissolve to a certain extent in the soil water, and ground rock phosphate is now a recognized source of phosphoric acid.

Basic slag, of course, owes its fertilizing value to the fineness of the powder to which it is ground. Basic slag is a waste product of the steel furnaces during the manufacture of steel from phosphatic rocks containing iron. For many years this slag was a nuisance to the iron companies, and accumulated in great heaps. About 1885 it was discovered that finely ground slag may be as good a source of phosphoric acid to crops as superphosphate in certain soils ; since then it has proved a profitable side line to the steel companies and a most valuable manure to farmers. It should be ground so small that 80–90 per cent. will pass through a sieve having 10,000 meshes to the square inch. Recent investigations have shown that basic slag has a very stimulating effect upon wild white clover (see p. 69), and to this combination much of the fertility of the grasslands of the country is due. Basic slag is rather more lasting in its effects than superphosphate, and it is also a home produced fertilizer ; these two facts no doubt influenced the Government when they decided, under the Land Fertility Scheme of 1937, to subsidize the application of basic slag to agricultural land.

COLLATERAL READING

A very elementary account of the soil is given by Sir E. J. Russell in *Lessons on Soil* (Cambridge University Press, 1920). One of the most readable descriptions is contained in *The Soil*, by Sir A. D. Hall (John Murray, 1921), though this needs to be augmented by more recent works. Comber's *An Introduction to the Scientific Study of the Soil* (Edward Arnold, 1936) is the most up-to-date book for general readers. For a description of methods adopted in soil classification consult *Soils—their Origin, Constitution and Classification*, by G. W. Robinson (Thomas Murby, 1938).

Manures and Manuring (Bulletin No. 36 of the Ministry of Agriculture, 1937) provides information of practical value, and a more detailed description of the nature and action of " chemical " manures can be found in *Artificial Fertilisers* (Bulletin No. 28, 1932). *Fertilisers and Manures*, by Sir A. D. Hall (John Murray, 1918), is valuable for the easy way in which the mass of information is presented to the not too technically minded reader. *The Use of Lime in Agriculture* (Bulletin No. 35, 1932) should be consulted. See also *Soils and Fertilisers*, by Sir A. D. Hall (John Murray, 1937). *Soil Conditions and Plant Growth*, edited by Sir E. J. Russell (Longmans, Green and Co., 1937), contains up-to-date information on all aspects of soil research.

CHAPTER III

THE BREEDING OF PLANTS

If the peoples of the world are to live they must have food, and this means that they must grow sufficiently large crops of different kinds of plants to suit their needs. Crops are much more important than stock, because without plants animals cannot exist. The so-called stock raiser has first to raise his plants, even though they consist entirely of grass, before he can feed his animals. The amount of cultivable land in the world is limited, and much farm soil is already being lost by erosion in North America and parts of Africa and Asia. In consequence of this, and the increase in population in many parts of the world, the necessity for increasing crop production is very real, despite the fact that at times, owing to unscientific methods of distribution, apparent over-production necessitates the spectacular destruction of food to maintain prices. The recent desire on the part of many countries to become as self-supporting as possible, as an insurance in times of war, is another factor.

In an intensively farmed country such as this it is essential that heavy crops should be produced, hence there is a continual striving to obtain better and better crop plants. The breeding of such plants is carried out by commercial seed houses, by private individuals, and by institutions supported, to some extent, by the State. This work, although it will always remain very much an art, becomes more and more scientific every season.

Actually, the science of plant breeding is of very recent growth indeed. Although wheat, for example, has been grown for thousands of years, it was not until the closing years of last century that it was even realized that its flower is self-fertilized. The world had to wait until 1901 before any definite scientific principles governing the art of plant and animal breeding were made generally known.

The improvement of crop plants by selection of likely looking individuals and their propagation by seed has, of course, been practised from time immemorial. Crop improvement by these means is bound to be slow and to become progressively slower, because it depends upon casual discovery ; the more intensively a crop is examined the less and less likely is an outstanding plant to be found. Fifty or sixty years ago it was comparatively easy to select out good plants from a cereal crop, because the average standard was low and the crops were very mixed. But now the average standard is much higher, and the crops are more even, so that improvement by selection alone is scarcely possible. The crossing of two plants, or hybridization, in the hope of obtaining something fresh, has been extensively practised since the latter part of last century, and with some success. But the progeny of such crosses so frequently seemed to " revert," or " throw back," to their ancestors in such an inexplicable way that the idea grew up that the offspring of crosses were naturally instable, and that in consequence little was to be hoped for in this line of investigation.

But in 1901 there occurred an event which put fresh life into the plant breeders. It was the republication of a scientific paper written by Gregor Mendel as far back as 1865. For nearly forty years it lay forgotten in the archives of a small Natural History Society at Brünn (now called Brno) in Moravia, and its author had been dead over sixteen years before the scientific world became aware of the principles he had brought to light. The incident provides an extreme example of the lag which may exist between the discovery of a principle and its application to human needs. Mendel explained for the first time that the offspring of hybrids may be expected to appear in definite mathematical ratios in different generations, and that the characters of plants could be regarded as individual entities, for they could be inherited separately. There is no need to go further into the study of Mendelism—explanations can be sought in the books referred to at the end of this chapter—but it is sufficient to say that the stimulus of these rediscovered principles has done a great deal for modern scientific plant breeding. Some of Mendel's statements have not borne the test of time, but of the value of his pioneer work there is no question.

One of the first crop plants to benefit from the new study of Mendelism was wheat. Two things influence the value of the wheat crop—yield and quality. British farmers grow almost the heaviest crops of wheat in the world, averaging about 17½ cwt. per acre. In Australia and the Argentine the yield is only 6¾ cwt., and in Canada 9½ cwt. per acre. But the quality of English wheat is, on the whole, inferior to that of imported wheat. By quality is meant the "capacity to make large, well-piled loaves," and this depends partly upon the starchy material in the grain, but more especially upon the gluten. British wheats are deficient in gluten, and are said to be "soft" and "weak"; imported wheats are "hard" and "strong." A two-pound loaf made from "weak" British wheat-flour gives a loaf with a volume of about 2,000 cubic centimetres only, whilst a similar loaf from Canadian flour has a capacity of over 3,000 cubic centimetres. The opening up of huge wheat-growing areas in America and Australia, and the public demand for a white, spongy loaf, did great damage to English wheat growing, and the acreage under the crop declined very seriously towards the end of last century. (During 1937 the area under the crop in Great Britain and Northern Ireland was 1,731,000 acres; in 1878 it was 3,000,000 acres.)

Biffen, at Cambridge, discovered that the strength or the weakness of a wheat variety behaves in accordance with the rules laid down by Mendel, and this at once opened up possibilities for improving the quality of English wheat. Biffen's first product was a cross between a variety called Red Fife, one of the strongest and best milling wheats, and Rough Chaff, a high yielding, poor quality variety. All the progeny of the first cross were found to be "hard," and when plants of this generation were grown next year there was segregation into hard and soft individuals: there were approximately three times as many hard-grained plants as weak-grained. Biffen selected some of the hard grains from this generation, and after several years was able to put on the market a new "strong" variety of wheat which he called Burgoyne's Fife. The fact that the yield of this good quality wheat subsequently proved disappointing does not detract seriously from its historical importance. The raising of this wheat was a landmark in the progress of plant breeding, for it demonstrated the value of Mendel's theory, and encouraged further attempts at building up a good quality, heavy yielding English wheat.

The very pertinent question may be asked—why could not some of the strong wheats from Canada or Australia be grown in this country? Many attempts were made to do this, but they were not very successful economically for two reasons. First, the yield of these imported wheats was much lower than that of English wheats for they were mostly spring wheats, which all yield less than winter sown wheats; and second, it was found that the strength or quality of the grain progressively diminished with every succeeding season. The climate, soil, and manuring of these islands undoubtedly reduced the quality. There was one exception to this, the variety Red Fife, mentioned earlier. Red Fife maintained its strength under English conditions, but its yield was small.

Biffen decided to make another attempt to graft the quality of Red Fife on to the yield of an English wheat. Numerous crosses between Red Fife and some of the heaviest yielding native wheats were made, until the number of plants of the second generation amounted to 80,000. Again it was noticed that the bulk of these had the hardness of Red Fife. Of the 80,000 plants some 200 were selected, and two years later these were whittled down to 24. The latter were tested for yield, and the four best selected. At the same time an attempt was made to assess the quality of the grain of the selected varieties, but this was by no means an easy matter because so little grain was available. There was not enough to permit of a baking test, so quality was assessed by estimating the nitrogen—it being assumed, with some accuracy, that the higher the proportion of nitrogen the greater the quantity of gluten. The physical nature of the gluten was assessed by the chewing test. This is a very simple test, but it appears to be as reliable as any other yet in common use. Some grains of wheat are chewed in the mouth until the starch has been dissolved away and a sticky pellet of gluten remains. The pellet is then placed in a shallow dish containing water ; if the gluten is of good quality for bread-making the pellet retains its shape for some time, whereas a pellet of poor quality gluten soon disintegrates.

By the fifth generation enough grain was available for a baking test, and it was found that all the four varieties were of better quality than any other English wheat. One of the four was selected and then grown on until in 1916 there was a stock of seed sufficient for general distribution. The new variety was called Yeoman. On good land Yeoman yields as well as almost any wheat, giving 40 cwt. or more per acre in many cases. On poorer land its yield is less satisfactory, despite its strong straw, which permits intensive manuring. It gives a flour of excellent baking quality, capable of making a good, marketable loaf without the admixture of imported flour. Since its introduction, Yeoman has taken its place in general farming as a really good yielding wheat on good, well cultivated land. From it has been selected Yeoman II., which has an even better quality of grain ; baking tests have shown that it will yield a two-pound loaf of well over 3,000 cubic centimetres. Yeoman has recently been crossed with White Fife by Engledow, and the variety Holdfast thus originated appears to be superior to Yeoman both in quality and yield.

It must not be imagined that the breeding of Yeoman

A plant breeder at work on wheat in a bird-proof " cage."

(*By permission of Messrs. Miln and Co., Chester.*)

has solved all the problems of the wheat growers in this country. It has demonstrated that high yielding, high quality wheat can be grown on good wheat land, but unfortunately there is not a great acreage of this type of soil in the country. No hard wheat has yet been introduced which can out-yield the old favourite, Squarehead's Master, on soils of medium fertility. The difference in price paid for hard wheat and soft wheat is not enough to compensate the British farmer for the reduced yield of the former. Until a hard wheat capable of yielding well on medium land has been bred, soft wheats will continue to occupy most of the wheat acreage in the British Isles. After all, soft wheats have their points. They have a large grain very suitable for feeding to poultry, and their straw is more plentiful and generally useful than that of the hard wheats—and straw means muck, which is essential to the fertility of the lighter soils.

The straw of wheat is a very important consideration in plant breeding. It is of no use increasing the weight of the ear if the straw cannot support it to harvest; if the straw "lodges," or "goes down," much of the crop is wasted, and the expense of harvesting is increased. One of the great problems of the plant breeder is to obtain varieties with a short, stiff straw capable of standing up to the large doses of nitrogenous manures now being used to increase the yield of grain. Little Tich, bred from a cross between two plants of Yeoman and selected for its shortness of straw, goes some of the way towards the ideal; whilst several other short-strawed wheats have already been bred. It has yet to be proved that these new varieties are suited to farm conditions.

The question of disease in crops is of the greatest importance, and quite naturally the farmer turns to the scientist and asks for varieties immune to such and such a complaint. He really does not know how much he is asking, for all sorts of considerations—such as time of ripening, speed of germination, thickness of epidermis, size and number of breathing holes (stomata) in the leaf, chemical nature of the cell sap, etc.—may determine the susceptibility of a plant to a disease. Immunity to one disease may be linked up with susceptibility to another disease, and so on. Nevertheless, some progress has been made in breeding disease-resistant plants, and wheat provides an illustration.

There is a very common fungus disease of wheat in this country called Yellow Rust. It takes the form of long yellowish or orange streaks on the leaves and stems during summer, and although it causes no spectacular failures the disease is estimated to reduce the yield throughout the wheat areas by 5–10 per cent. Biffen found that susceptibility to Rust behaves as a Mendelian character, and armed with this knowledge he proceeded to raise a Rust-resistant wheat. About 1908 he crossed a very Rust-resistant wheat from Russia, called Ghurka, with Squarehead's Master. The offspring were all susceptible to the disease. The second generation, that is, the plants grown from seed formed from these self-fertilized, susceptible plants, included both susceptible and immune individuals. Approximately three plants out of every four were susceptible, but Biffen knew from Mendelian principles that the immune plants would retain their immunity. He selected from these immune individuals a form which seemed to have good cropping powers, and propagated it under the name of Little Joss. This new variety is immune to Yellow Rust, and unlike

Yeoman does well on light soils. Its quality is not so good as that of Yeoman, but it has good straw and can be sown either as a winter wheat or an early spring wheat.

These two varieties of wheat are of outstanding importance because of the encouragement they gave to breeders studying the new Mendelian principles. But, of course, many good wheats were raised long before Mendels's work became generally known. Squarehead's Master has long been a favourite on many farms, but it was not bred—it is supposed by some authorities to have originated in a natural cross, between Golden Drop and Scholey's Squarehead, selected by Teverson. Wilhelmina wheat, a very heavy yielding and popular variety with a soft grain, was bred in Holland about 1890. It arose from a cross between Squarehead's Master and a Dutch variety Zeewsche, crossed back with Squarehead. A plant breeder may make a lucky cross and get what he wants straight away. But more usually plant breeding is a long and extremely laborious process extending over many years; science has helped to smooth out some difficulties and will probably do more as knowledge increases, but plant breeding will always remain an art rather than an exact science.

On many of the lighter arable farms in England barley is a more important crop than wheat. The barley grower aims at obtaining a sample which will be purchased by a maltster or brewer, because a malting sample fetches very much more per hundredweight than barley used for feeding to stock. Here, as in the case of wheat, there are two distinct problems—those of quality and yield. Until quite recently malting barley was purchased entirely on its appearance. The buyer looked for a dry, uniform sample having, amongst other things, a pale lemon colour and a very finely wrinkled "skin," together with a white, mealy interior. He knew that if his eye was satisfied with the sample, his ale would be clear and pale and would keep, but he did not know why. He had to wait until 1902 before Beaven supplied the reason. Beaven showed that the appearance of a good malting barley is related to a low percentage of nitrogen ; bad malting barley has a relatively high proportion of nitrogen. Generally speaking, a good malting barley has less than 1.5 per cent. nitrogen, calculated on the dry matter of the grain. It was discovered later that some varieties of barley naturally produce grains low in nitrogen content ; but at the same time it was also evident that the weather, particularly towards harvest, can influence the proportion of nitrogen to a considerable extent.

The problems facing the plant breeder were therefore very complicated. He had to raise a barley naturally low in nitrogen, capable of giving a good yield per acre, possessed of a stiff straw, and able to ripen rapidly. The earliest large scale scientific attempt in the British Isles to improve barley was begun by Hunter in Ireland about 1900. The first thing was to collect and examine as many varieties as possible, and study their suitability both to the farmer and brewer. Of the numerous types, a variety called Archer seemed the most likely. This is a narrow-eared barley of high quality, but rather weak straw and a tendency to lateness in ripening. A selection was made in 1904 of a promising plant of Archer, and this variety by 1910 was giving a yield of approximately 1½ cwt. more per acre than the average for Ireland. It is interesting to note here that the Danes, in their experiments carried out from 1883 to 1903, also fixed upon

Archer as being the best variety. Their type, however, was called Prentice—it was derived from an Archer barley imported from England.

But the weakness of Archer straw was a great disadvantage, so Hunter crossed his improved Archer I. with a variety called Spratt having a very stiff straw but inferior quality grain. From the progeny of this cross was selected a barley which seemed to combine the quality of Archer and the straw of Spratt. It is a narrow-eared type like Archer, but has a brighter grain, is earlier in ripening, and yields more. Grown both on light and heavy soils its nitrogen content is less than that of Archer. The new variety was named Spratt-Archer. It was extensively tested out between 1919–23, and in a very few years it ousted almost all other varieties on the light barley soils of England.

Archer barley, however, is not suited to soils of high fertility, especially those in the west of England. In these districts broad-eared barleys have been much more successful, particularly since the introduction of the Goldthorpe variety about 1890. Goldthorpe gives a very good malting sample but has a straw which becomes brittle below the ear just before harvest. Losses through the breaking off of the ear may be considerable. To overcome this serious disadvantage Beaven in 1905 made a cross between a type of Goldthorpe called Plumage, and Archer, which has a particularly short "neck," or portion of straw between the ear and the first sheathing leaf. From this cross originated the variety called Plumage-Archer, which is a broad-eared barley capable of yielding large crops of good quality grain, and having the strong neck of Archer. This is now the most widely grown of the broad-eared barleys.

Oats have given the plant breeder a double problem, because, unlike other cereals, the straw of oats may be just as valuable as the grain. The grain of oats is used chiefly as a food for farm animals and horses, though a considerable amount is consumed by human beings in the form of porridge and oatmeal products. The straw of oats is usually chaffed up into small pieces and fed to stock. In the more northerly farming districts the feeding value of oat straw is very high, and it is claimed that a bullock can be fattened upon nothing else but oat straw and turnips. Oats, therefore, constitute a dual-purpose crop. On light soils the straw may be more important than the grain, on good soils the position may be reversed. Consequently there are very numerous varieties of oats, all of them supposed to have special advantages in certain districts and on certain soils.

The raising of new varieties of oats by hybridization did not start until about 1890. The outstanding varieties up to then—Sandy, Potato, Hopetoun—were chance discoveries. The " Fellow " oats, such as Early Fellow and Long Fellow, were selections made as the result of systematic searches through growing crops. The first hybrid oat to be marketed was raised by Dr. John Garton, of the firm of Gartons Ltd., Warrington. It was introduced in 1892 under the name Abundance. It was a cross between White August and White Swedish, and it is still one of the best varieties for fertile, well cultivated land, owing to its high yield of grain and fairly early ripening. Since 1892 Gartons have introduced a large number of oats designed both for good and for less fertile soils, including such varieties as Bountiful, Waverley, Earl Haig, Captain, and Marvellous.

This last variety, Marvellous, illustrates very well the complexity of the task facing the would-be plant improver. Marvellous was derived from a cross between a white-grained oat and a grey-grained oat. The former in its turn originated in a cross between the Wild Oat and Grey Winter; the latter was a hybrid between the Wild Oat and Goldfinder (a variety bred by Gartons in 1901). The pedigree of Marvellous is, therefore:

$$\underbrace{\underbrace{\text{Wild Oat}\quad\text{Grey Winter}}_{\text{White grained oat}}\qquad\underbrace{\text{Wild Oat}\quad\text{Goldfinder}}_{\text{Grey grained oat}}}_{\text{Marvellous}}$$

Marvellous was a selection made with the idea of obtaining an oat which would be winter hardy, and it was put on the market in 1921 after winter sowing. Most oats, of course, are sown in spring, and an improved winter variety was very much required. For some seasons after the introduction of Marvellous the winters were mild and the variety did very well. Then came one or two severe winters, and Marvellous was found not to be truly winter hardy. As a spring oat Marvellous often does extremely well, but this case does show how the plant breeder may be led to false conclusions because of slight changes in climatic conditions.

No other *hybrid* oat has yet attained to the high position enjoyed by Abundance. The well-known Victory oat resulted from a selection of the Probsteier variety at the Swedish Plant Breeding Station at Svalöf, and was marketed in 1908. Golden Rain is another earlier selection from the same stock. One must not assume, however, that because most of the popular oat varieties in this country have been selected, and not hybridized, that no science has gone into their production. The choice of a special form from thousands very similar to it requires a considerable degree of knowledge and observation; selection is just as essential to the hybridizer as to the man who prefers to find his plants ready made.

Hybridization of oats is being practised now, however, not only with yield and quality as the immediate object, but also in an attempt to overcome the ravages of the Frit fly. This is an insect which in spring lays its eggs close to oat plants, and its maggot lives on the juicy growing point. The main shoot of the plant is destroyed, and the side shoots either develop too late to flower or else give a much reduced yield. It has been found that certain oat varieties are much less susceptible to attack than others, and attempts are being made to combine this resistance with good yielding capacity and good grain.

Next to the cereals the potato is the most important crop grown here for human consumption. The area under the crop in 1937 was 455,000 acres, and the yield amounted to 3,126,000 tons. A very great deal of scientific investigation has gone into the improvement of this crop, though much remains to be done, especially with regard to the breeding of varieties resistant to Blight and Virus diseases (see pp. 114–19). Present-day potatoes are much superior to the small, irregular, highly flavoured potato of a century ago.

The improvement of the potato really dates from the years of the great famine in Ireland (1845–1847), when at least half of the potato crop was destroyed by the Blight fungus (*Phytophthora infestans*), causing widespread misery and starvation. Determined efforts were made to find a variety immune to this disease, and they are still being made, but so far with indifferent success. Until such a variety is found, reliance will have to be made on protective spray fluids such as Bordeaux and Burgundy mixtures (p. 114)

Since the middle of last century, too, a lot of attention has been paid to other aspects of the potato crop. A reasonably heavy yield is a *sine qua non*, but yield alone does not mean a satisfactory financial return per acre to the grower. Nowadays the public demands a quality potato. The tuber must be of a medium size, preferably of an oval or kidney shape; very big and very small potatoes are of little market value, for obvious reasons. The " skin " of the tuber must be thin, and its " eyes " (which are really collections of buds) must be few, and shallow; otherwise there is considerable wastage in peeling. The flesh must be white, for the public will not buy a yellow-fleshed potato despite its greater feeding value. It must cook to give a bulky, light flour which does not readily discolour. Chip potato merchants require special characteristics in their potatoes. Unless the tubers themselves have these qualities, the variety is not worth growing, because merchants refuse to buy. But in addition the farmer must have early varieties which will catch the profitable market just as the over-wintered supplies of potatoes are giving out, and he needs varieties which will resist insect and fungus enemies.

The would-be improver of potatoes is in a rather curious position. In the first place, it must be clearly understood that the ordinary potato as eaten is just a swollen piece of underground stem. When these stems, or tubers, are planted they are often spoken of as " seed," but they have nothing in common with true seed, which can be formed only from a flower. In the ordinary course of cultivation a potato variety propagated by tubers retains its characteristic shape, colour, structure, and so forth, indefinitely. Its cropping power may suffer, or "degenerate," on account of virus disease, but not its general nature. On the other hand, a potato which is reproduced from true seed, the seed within the "apple" or berry formed from the flower, does not "come true." It splits up into a bewildering number of different forms, some similar to, others very different from, their parents. Furthermore, very few commercial potato varieties form perfect flowers. In some the flowers are seldom found at all, in others the flowers develop, but drop off before they mature; others again form flowers but no pollen. The choice of parents for hybridizing experiments is consequently limited, and the breeder must know his varieties very thoroughly before he begins operations.

Whilst it is an easy matter to cross two fertile varieties of potato and obtain a large and diverse progeny, the selection of the most suitable of the latter demands knowledge, careful observation and skill, and a ruthlessness in the destruction of unwanted types. It is not a difficult matter to select for shape, thinness of skin, paucity of eyes, and other characters of the tuber, and it is only a shade less easy to assess cropping quality. It is not so easy to choose the varieties resistant to Wart Disease and Blight, and numerous new potatoes of a promising kind have had to be scrapped when they have been found to be highly susceptible to either or both of these diseases. On the other hand, once the selection has been made, the breeder does not have to worry as to whether his new variety will come true or will "revert," after the manner of cereal introductions; he knows that so long as it is propagated by tubers it will retain its characteristic features.

Nowadays, it is highly desirable that new potato varieties should be immune to Wart Disease. One of the most consistently successful breeders of immune potatoes is Mackelvie, living in the Isle of Arran, situated off the west coast of Scotland only a short distance by steamer from Glasgow. Ally, Arran Banner, Arran Pilot, Arran Consul, Arran Victory, Arran Crest, Arran Chief, Arran Comrade, are amongst the best known. Findlay, also in Scotland, has produced the famous immune varieties—Majestic, Catriona, and Di Vernon, and the non-immune Up-to-Date.

So far the study of genetics has not been of much assistance in the breeding of commercial potato varieties. Potatoes are very complex from a genetical point of view, and a great deal of analysis, or sorting out of characters, will have to be done before the behaviour of the latter can be forecasted under different crossings. A lot has already been accomplished at Cambridge by Salaman and his co-workers. For example, it has been shown that immunity and susceptibility to Wart Disease behave as Mendelian characters. The continuance of such work is essential if the breeding of potatoes is to become more precise than it has been hitherto. Art, more than science, together with a fair slice of luck, has so far been responsible for most of the well-known potato varieties.

Sugar beet is another important crop in many parts of England; in 1937 over 306,000 acres were devoted to the crop, and 7,818,000 cwt. of manufactured sugar were made from the roots. Not only is the crop itself a valuable one on account of the cash returns for the roots themselves, but it is important because of the employment it provides for agricultural workers, casual labourers in the field during the growing season, workers in the beet factories, transport workers, and so on. The high standard of cultivation demanded by the beet is also a national asset.

In England the beet sugar industry dates from about 1920, though there was a factory working at Cantley in 1912. In Europe the industry started about 1800. The sugar beet is a kind of mangold in which the proportion of sugar has been greatly increased by careful selection throughout the last 100 years. It is derived from a wild plant commonly found along certain coastal districts in Europe; some of these wild beet have a very high percentage of sugar, as much as 20 per cent., but their roots are small, tough, and badly shaped. The first real attempt to improve sugar beet was made by Achard in Germany towards the end of the eighteenth century. He picked out from a large number of forms a type with a long, tapering, white-fleshed root, which is the sort in general cultivation to-day. His work was extended by Louis de Vilmorin in France. To make sugar beet a profitable crop it was necessary to do three things—to raise the percentage of sugar in the individual root, to increase the weight of roots grown per acre, and to make the roots easy to lift, because the early types were almost entirely buried in the ground, like parsnips. These improvements have been brought about almost entirely by selection.

To increase the sugar content only those roots having much sugar were propagated by seed. At first the concentration of sugar was determined by immersing the root in salt solutions of various strengths; those roots rich in sugar sank, whilst the less rich floated. This was a very crude method, and in 1862 a method of estimating the sugar percentage by means of the polariscope was introduced. In this method a beam of light is caused to shine through a long narrow tube containing a known quantity of beet juice ; the beam of light is deflected in accordance with the density of the solution, and it is then a simple matter to calculate the sugar percentage in the whole root. It is not necessary to examine all the root ; an instrument called a borer is thrust through the root in one or two places, and cylinders or " cores " of tissue are extracted. By intensive selection throughout the last fifty years the yield of clean washed beet has been raised to about 12 tons per acre, and the sugar percentage to 18–20 per cent., whilst in addition a more upstanding, less deeply-rooted form has been evolved, much easier to lift than earlier types.

Sugar beet is naturally cross-fertilized, and this makes the work of the plant breeder very difficult, much harder than in the case of cereals. As already explained, the cereals are self-fertilized, so that there is very little risk of crossing with undesirable plants, and a variety once introduced remains true, barring accidents. It is, however, impossible to maintain a true variety of sugar beet, because of its habit of cross-fertilization. Sugar beet will even cross-fertilize with mangolds, and for this reason raisers of sugar beet varieties take great pains to ensure that no mangolds are allowed to flower within about three miles of their beet seed crops.

The modern method of breeding sugar beet is first to select " mother " roots having desirable features ; each plant the following season (for sugar beet is a biennial plant) is covered with a canvas or silken bag to keep out foreign pollen, and the individual flowers on this plant are allowed to fertilize amongst each other—it is a form of " selfing." The progeny of the seed thus formed are grown separately, and their sugar and other characteristics carefully analysed. If an individual plant thus tested is found to be good, it is crossed with another plant having similar characteristics, and the seed grown on for distribution. The idea of the " selfing " is to study the constitution of the individual plants, but in doing this the vigour of the plants is much reduced, and only a small amount of seed becomes available. The controlled crossing of two approved plants restores vigour and powers of seed production.

Selection is also necessary to prevent " bolting," *i.e.* the production of seed stems during the first year of growth. The bolting characteristic has been shown to be a Mendelian character, but so far the Mendelian theory has been of little use in the improvement of the crop. By scientific selection methods the average percentage of sugar in sugar beet has been raised from about 7.8 per cent. in 1850–60 to over 18 per cent. in recent years. Weather conditions, of course, cause fluctuations in sugar content.

Although turnips, swedes, and mangolds occupy only about one-thirteenth of the total arable acreage of Great Britain and North Ireland, they are still very valuable crops. They, together with such things as kale and cabbages, form the so-called " roots " which are fed to sheep, dairy cows, and fattening bullocks. The present-day turnip and mangold are much better shaped, and yield more heavily, than those of last century. Until recently selection was practised almost entirely for appearance and size. The farmer likes to have a well-shaped root and he likes a big crop, not realizing that the larger the root the higher the proportion of water it contains. As it is, a white turnip may contain 91–92 per cent. of water; that is, a farmer carting 100 loads of turnips from a field may be carrying 92 loads of water and only 8 loads of solid matter.

The Danes were the first to realize the need for quality in "roots," their investigations beginning about 1883. They found that 1 lb. of the *dry* matter of turnips is equal in feeding value to 1 lb. of barley, and it became obvious that what matters in turnip growing is not the gross yield of the roots, but the quantity of dry matter per acre. With this ideal before them, the Danish investigators began to select plants having a good dry matter analysis combined with favourable yielding capacity; they gradually discarded the inferior strains and encouraged farmers to grow the new types.

Turnips and mangolds behave very similarly to sugar beet, in that they are naturally cross-fertilized. It is consequently very necessary to keep seed crops of these plants well isolated. They are frequently grown in small patches surrounded by large areas of potatoes or cereals. It is also impossible to keep turnips and mangolds genetically pure in the way that it is possible with cereals; there is bound to be some variation in the plants of any variety of turnips because of this cross fertilization, but it is the business of the plant breeder to keep this variation down to a minimum by continued selection.

Turnips and swedes may suffer severely from a fungus which causes Anbury, or Finger-and-Toe disease. Affected roots become distorted, knotted, or swollen, and rot away. Recently, attempts have been made to select strains of turnips resistant to this disease, and with some success. Varieties such as "Bruce" and "Wilhelmsburger" are much less susceptible to Finger-and-Toe than most other varieties, and they also resist another fungus disease, "Mildew," to a considerable degree. Unfortunately, they do not yield as heavily as susceptible varieties, but they can, and do, give reasonable crops on land which would not grow other varieties.

There is no point in putting new varieties of crop plants upon the market unless they are superior to existing varieties. Large-scale testing of cereal, root and potato varieties is being carried out by the National Institute of Agricultural Botany, which has its headquarters at Cambridge and numerous sub-stations dotted about England and Wales. At these centres crop varieties are tested with all the careful precautions demanded by statistical workers. The information thus collected enables reliable recommendations to be made concerning the most profitable varieties for the various districts.

COLLATERAL READING

A brief account of the methods employed in the raising of new breeds of farm plants is given in *Crop and Stock Improvement*, by A. B. Bruce and H. Hunter (Ernest Benn Ltd., 1926). The technique of hybridization, chiefly from a horticultural standpoint, is explained in a simple manner, and some account is given of the laws of inheritance by W. J. C. Lawrence in *Practical Plant Breeding* (Allen and Unwin Ltd., 1937). For an account of the Mendelian theory the reader should consult *Mendelism*, by R. C. Punnett (Macmillan), or *Mendelism and Evolution*, by E. B. Ford (Methuen, 1934). *Recent Advances in Agricultural Plant Breeding*, by H. Hunter and H. M. Leake (J. and J. Churchill, 1933), deals with farm crops in both temperate and tropical climates. For information on wheat breeding consult *Wheat Breeding Investigations at the Plant Breeding Institute, Cambridge*, by R. H. Biffen and F. L. Engledow (Ministry of Agriculture and Fisheries, 1926). A very interesting account of the improvement of wheat in Canada is given in *Essays on Wheat*, by

A. H. R. Buller (Macmillan, 1919). For fuller information relating to the improvement of barley and oats consult H. Hunter's two books, *The Barley Crop* (Ernest Benn, 1926) and *Oats* (Ernest Benn, 1924). Details regarding the potato crop can be found in *The Potato*, by T. P. McIntosh (Oliver and Boyd, 1927). A brief account of the improvement of sugar beet is given in Bailliere's *Encyclopædia of Scientific Agriculture* (1931). See also the *Journal* and interim reports of the National Institute of Agricultural Botany.

CHAPTER IV

GRASS AND PASTURE PLANTS

THE climate of these islands is such that grasses, clovers, and other plants found in grassland grow extremely well. The rainfall is evenly distributed throughout the year, droughts are not common, and the frosts of winter are usually not sufficiently severe to do serious damage to the herbage. No other country in the world, with the exception of New Zealand, enjoys climatic conditions so favourable to the production of grass. Our best grassland is consequently very good, but at the same time there are many thousands of acres of grass in very poor condition indeed, due to mismanagement, understocking, and ignorance of new and improved methods of treatment.

Before explaining modern ideas about the treatment of grassland it is necessary to be a bit more precise about the term "grassland." Broadly speaking there are two types of grassland, rotation grass and permanent grass. Rotation grass is an essential part of most forms of arable farming, and it is of a very temporary nature; it is, indeed, frequently referred to as "temporary" grass. In the old Four Course Rotation, or Norfolk shift, the sequence of cropping is: 1st year Wheat; 2nd year Roots; 3rd year Barley; 4th year Clover. The clover and grass seeds are sown with the barley in the third year, and when the cereal has been removed after harvest the clover and grasses can be lightly grazed that winter, cut for hay in the early summer following, and possibly grazed again before being ploughed under in preparation for the wheat crop which is usually sown in October or November.

The clover crop consequently occupies the land for about 15 months, during which time a certain amount of fertility accumulates in the soil, due to the formation of a mass of tiny grass rootlets and the special action of the clover in accumulating nitrogen from the air. But in many districts it is found preferable to allow the " seeds " to remain down for two, three, four, or more years before ploughing them under. Such leys, although they may be of long duration, still form part of an arable system of farming. From the very start it is the intention of the farmer to plough them up eventually and crop the land with something else.

Permanent grassland, in the sense of the word usually accepted to-day, is never ploughed, or is ploughed at such enormous intervals of time as to amount to the same thing. There are many different kinds of permanent grassland ; at one extreme there are large areas of poor natural hill grazings in the north and west, and at the other extreme the very rich and highly prized fattening pastures of Leicestershire and other counties. On the former a sheep may need to roam over many acres in its search for sustenance, whilst in the latter a full-grown bullock may, without any extra feeding, find enough nutriment on one acre to make it grow fat. There are the rich salt marshes round our coasts and the thin dry pastures of the Downs, the spongy grasslands on peaty soils and the acid grasslands in the neighbourhood of large industrial smoky areas. Variety of this sort makes it difficult to deal with the problem at all concisely.

Much of the permanent grass is used as pasture, that is, it is grazed by animals throughout the seasons. Some of it is meadow land, that is, it is shut up for hay from May to July, though it may also be grazed at other times of the year. In other cases hay crops may be taken at irregular intervals.

Now what has modern science to offer the farmer whose living depends partly or wholly upon his grassland? It has a great deal to offer, because tremendous strides have been made in the improvement and management of herbage plants during the last twenty years. The new knowledge is well appreciated in scientific circles and by certain progressive farmers, but it has only just begun to filter through into general farming.

In the first place let us consider the separate plants which constitute the herbage of grassland. It is very remarkable how few species of grasses and clovers (using " clover " in a wide sense) are used by farmers. About 130 different species of grass are found in this country—only half a dozen are at all widely used on the farm. Not more than four or five of the numerous clover tribe are sown to any large extent in seeds mixtures. The most useful grasses, experience tells us, are Perennial Rye grass, Italian Rye grass, Cocksfoot, Timothy, Rough-stalked Meadow grass and certain small Fescues; the most widely used clovers are Red clover, White clover, Alsike clover, Trefoil, and possibly Lucerne.

Prior to the beginning of the nineteenth century it was not at all easy to get suitable supplies of seed of these grasses and clovers, or indeed of any grasses and clovers except the rye grasses, red and white clover. Clover seed was imported from Flanders and sown by itself as early as the middle of the seventeenth century, and perennial rye grass was obtainable in a more or less pure condition at about the same time. A century later, that is, about 1760, cocksfoot seed was imported from Virginia and timothy seed from the States. During the early part of the nineteenth century communications improved, steam as a source of power became available, and grass and clover seeds could be obtained much cheaper, and also in a purer state, than at any previous time. These dates are important, for it is necessary to remember that the practice of forming long duration or permanent grassland from the sowing of seeds mixtures, compounded from specified amounts of pure seeds, is not much more than 170 years old. The much commoner plan was to use sweepings from hay lofts and barns.

Naturally, these sweepings, like impure samples of commercial seeds, contained many weed seeds and were of poor germination quality. The formation of good permanent grass was consequently a chancy and a lengthy business, and a good pasture once formed was not a thing lightly to be broken up again. Hence there grew up a great respect for a piece of old turf, which towards the end of the nineteenth century developed into an uncritical adoration. Old pasture became almost sacred in the estimation of landlords, and severe financial penalties, amounting in some cases to a fine of £50 per acre, were held over the heads of incoming tenants lest they should plough out this old turf. More will be said about this aspect of grassland. Meanwhile it is necessary to consider how modern investigation has improved some of the plants required in grassland formation.

The first grass ever to be cultivated alone for its seed was perennial rye grass. It was grown in Oxfordshire early in the seventeenth century, and found its way later to all the temperate countries of the world. The merits of the grass, such as its rapid germination, quick establishment, palatability, yield, and so on, led to the development of considerable seed-growing industries in Ayrshire, Northern Ireland, and elsewhere. Certain types of perennial rye grass were found to give seeds that were larger and had less husk than others ; size and weight came to be regarded as the principal things to look for in perennial rye grass seed, and buyers were encouraged to buy perennial rye grass of high bushel weight regardless of the type of plant to which this seed would give rise.

The result of this policy of insistence upon heavy seeds was the losing sight of the main purpose for which perennial rye grass is grown—namely, the production of leaves. Continual cultivation for seed and yet more seed led to an unconscious weeding out of the leafy types with comparatively few flower stalks, and a concentration upon plants with many flowering stalks and relatively few leaves.

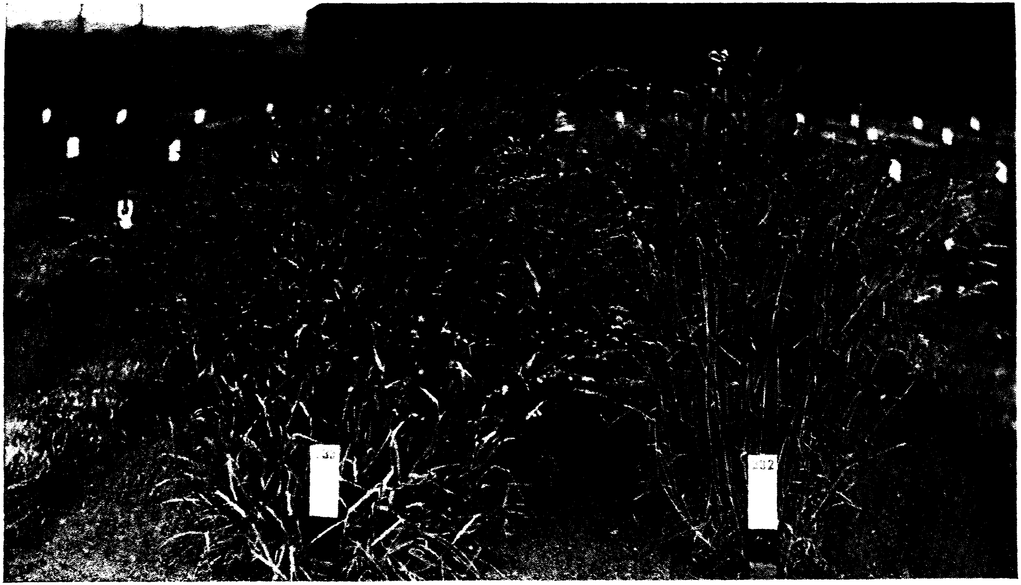
The consequence was that towards the end of last century perennial rye grass began to get a very bad name amongst intelligent agriculturists, especially for permanent grass. Yet at the same time careful examination of the herbage of good pastures in different parts of the country showed that perennial rye grass and a dwarf form of white clover are by far the commonest constituents of first-class turf. There existed the apparent anomaly of a despised grass species forming the bulk of the best fattening pastures in the country. Gradually it became realized that perennial rye grass is an extremely variable plant, existing in all sorts of forms, from the very leafy and long-lived to the very stemmy and short-lived. The former plants came to be designated " indigenous " ; they were also called " evergreen," because the tips of their leaves are not so liable to turn brown in winter as those belonging to the latter, or " commercial " types.

This was the position during the early years of the present century. One valuable source of " evergreen " perennial rye grass was discovered on certain very old pastures in Kent ; this seed gave rise to rather small plants of a very leafy nature, which had remarkably few flower stalks and a long length of life. This Kentish indigenous, evergreen rye grass commanded respect and enhanced prices from those farmers who knew a good grass from an indifferent one, but the amount available was relatively very small.

Then came the war period, which, although it stimulated food production and the ploughing up of much grassland, did not encourage research into forage plants. After the war, however, occurred an event which has had far-reaching effects upon the improvement of grasses and grassland. This was the establishment of the Welsh Plant Breeding Station at Aberystwyth, with Professor R. G. Stapledon as Director. The chief duty of this station was to improve the supply of grasses and leguminous plants, and naturally it took a great interest in perennial rye grass. It collected different types, or strains, of the species from all parts of the country and from abroad, grew them, compared them, criticized them, analysed them, and published reports on them. In this way it was able to establish and drive home the very considerable advantages possessed by certain indigenous strains over the majority of commercial strains in persistance, leafiness, freedom from winter scorch, and relative freedom from flowering stems. It was shown that strains from the Weald district of Kent, from certain districts of New Zealand, and from parts of Sweden, are much superior to ordinary unclassified commercial types.

Further, the Welsh Plant Breeding Station was able to develop new methods of cross-breeding grasses so as to combine the desirable qualities of two or more promising plants into one strain. This in itself was a notable piece of work, judged by purely scientific standards. Its commercial results are only just being realized by farmers, for it is a long and tedious business raising and marketing a new variety of plant. But in the Aberystwyth strain S.23 and in some strains from commercial houses we have pedigree perennial rye grasses which in some districts have proved extremely valuable.

Cocksfoot is another grass which has been the subject of much research during recent years. It is a grass which is commonly found in large tufts in orchards and rough pastures, having a very flat shoot and a flower-head shaped like the toes of a bird. The common name for this species used to be rough cocksfoot, for its foliage was harsh and rough to the touch, and the general coarseness of the plant made it much disliked by farmers, even for hay. But careful investigation showed that there is as much variation between plants of cocksfoot as between plants of perennial rye grass, and it became possible to select plants with much smoother, more palatable leaves than others. It was possible to distinguish between early-maturing plants with numerous flowering stems, and late-flowering plants with a denser leafage at the base.



Two different strains of Cocksfoot.

Note the extreme leafiness of No. 233, an indigenous type, and the erect, stemmy nature of No. 232.

(By permission of Messrs. Gartons, Ltd., Warrington.)

The former are more suited to mowing for hay, and the latter for grazing. Strains from Denmark and France are suited to hay purposes, strains from New Zealand (such as the Akaroa) and indigenous types from this country make excellent grazing plants. Hybrid cocksfoots, specially bred for persistence under pasture conditions, are now available. These improved plants have brought cocksfoot into favour on light soils unsuited to perennial rye grass, largely because the habits of the plant are now better known, and it can be controlled by varying the management of the pastures.

The improvements to perennial rye grass and cocksfoot just described have resulted in an increased productivity which the uninformed and unobservant might find it difficult to believe. To a lesser extent the plant selector and breeder have worked upon timothy and rough stalked meadow grass, but in the case of no other grass species have the improvements been so valuable as in rye-grass and cocksfoot.

Clovers have come in for a great deal of attention from all sorts of agricultural scientists during the past thirty years, particularly red clover and white clover. It is a difficult task to assess the value of our new knowledge concerning these two species, but the national agricultural wealth must be very much greater on its account. Clovers are leguminous plants belonging to the Family Leguminosæ, all members of which have on their roots small swellings, called nodules. These nodules are not, as was at one time supposed, symptoms of disease. They are caused by certain bacteria which feed upon the clover whilst taking nitrogen from the air to build up their own microscopic bodies. Eventually the clover obtains some of this nitrogen from the bacteria by processes which have not yet been fully investigated. This removal of nitrogen from the air is a very remarkable thing, because plants other than leguminous plants have to get their nitrogen from the soil in a dissolved form, and nitrogen both as a fertilizer for crops and as a food for stock is an expensive element to buy.

Clovers, however, have roots, stems, and leaves which are very rich in nitrogen compared with those of other plants, and this extra nitrogen is obtained at no cost to the farmer. Moreover, as Virtanen has recently shown, the clover excretes combined nitrogen into the soil during its lifetime, and grasses growing in the immediate neighbourhood are stimulated by it. When clover is ploughed under during the breaking up of a temporary ley or permanent pasture, the roots decay and gradually release the stored nitrogen for subsequent crops.

Hence clovers are of extreme importance, and no intelligent farmer would dream of sowing down a field to " grass " without including some clover. The most valuable clovers are Red Clover (*Trifolium pratense*) and White Clover (*Trifolium repens*), and we must now consider what recent research has done with these two species.

Red Clover has been known to farmers in this country since about 1630, Sir Richard Weston being credited with its introduction. But although the plant has been grown here for three hundred years it is only during the last two decades that the possibilities of the plant, and also its limitations, have been properly realized. As the result of long and tedious investigations conducted at the Welsh Plant Breeding Station and elsewhere, we can now group the numerous different types of red clover into three main classes—namely, wild, early-flowering, and late-flowering red clovers.

For the present the wild type may be disregarded, since it has been shown that it is a plant unlikely to influence farming to any great degree. The other two types are extremely important to rotation grassland, and the chief value of the investigations carried out upon them during the last twenty years lies in the discovery that some strains are much more productive and longer lived than others. Another service which these researches have performed is to kill the name " cowgrass " formerly applied to these clovers. The name " double-cut cowgrass " was used until recently to describe any red clover which could give two cuts of hay in a season, and the name " single-cut cowgrass " to any red clover which could not give more than a single hay crop.

Now we know that strain in red clover is of the greatest importance, and that the beauty of a sample of red clover seed is not necessarily an index of its utility as a producer of herbage. The best cropping strains frequently have seed which looks inferior to less valuable foreign strains. From repeated experiments the farmer may rest assured that red clover seed grown in this country is as a rule superior to imported seed, and that seed imported from temperate climates is likely to be superior to seed coming from warm countries. Strains of red clover from certain counties and districts of England and Wales are superior to other strains from other districts. Thus, the value of red clovers from the Eastern Counties, Dorset, Vale of Clwyd, Cornwall, and the Cotswolds has been amply demonstrated. Hence, under the provisions of the Seeds Act, 1920, vendors are compelled to state the country of origin of their red clovers, as a guide to farmers.

Recent work on red clovers has emphasized the extremely temporary nature of the early-flowering type, which usually lasts only one harvest year ; and also the fact that very few strains of the late-flowering type endure profitably for more than three seasons. The Montgomeryshire extra late-flowering red clover and the Cornish Marl are the longest lived strains, but even these give very little yield after four seasons. Another discovery which is proving of value is that the late-flowering types give a heavier yield of hay than the early-flowering types, despite the bigger and broader leaves of the latter. Of course they do not give as much grazing after the hay has been removed, nor in the stubble during the first year of their existence.

If we agree with Stebler, the celebrated Swiss agriculturist, who said many years ago that the development of red clover as a farm crop has had an influence on rural and national life even greater than that of the potato, the importance of this recent work needs no further emphasis.

If increased knowledge of the red clover plant has put greater power into the hands of the man farming rotation grassland, even greater benefits have been derived for grassland as a whole from the study of Wild White Clover. This small, creeping plant, which is usually only noticed by the non-farming population when it is in full flower during the summer, must be regarded as one of the most valuable of all farm plants. Certain it is that the value of farm land has been increased to an enormous degree by the extended growth of the species.

True wild white clover is a very different plant from the cultivated or Dutch white clover. It is smaller, longer lived, and grazes much better. It is rich in protein, the flesh-forming food, and comparatively rich in calcium and phosphorus, both of which are essential to the formation of bone and milk. It grows rapidly, and accumulates much fertility.

These facts were not discovered all at once. It was not until 1886 that the persistence of the true wild white clover, as opposed to the cultivated type, was first demonstrated by experimental plots. The source of supply was very old pastures in Kent, which were mown at intervals to obtain seeds of crested dogstail grass, and evergreen perennial rye grass ; wild white clover seed was then a side-line, a by-product. It is now the principal motive, and the grasses are relatively unimportant.

About 1906 it was discovered at an experiment station called Cockle Park, in Northumberland, that basic slag had a remarkably stimulating effect upon wild white clover growing in pasture, and this in turn greatly increased the number of stock which the land would carry throughout the season. The land here was a cold, poor clay, but similar results were obtained some years later on a thin, light, chalky soil on the South Downs not far from Newhaven, in Sussex. It gradually became realized that the interaction of phosphatic manures, especially basic slag, and wild white clover, offers one of the best methods of improving grassland. On some soils the addition of potash fertilizers also is found necessary before the white clover can be stimulated. Later still it was realized that wild white clover develops very rapidly from seed if conditions are suitable. It sends its runners over the surface of the soil and soon binds the grasses together. The result is that a good turf is formed very much earlier than would be the case if wild white clover were not included in the seeds mixture.

Some idea of the increasing respect for this plant may be gathered from the fact that whilst in 1907 wild white clover seed could be obtained at 1s. 6d. a pound, by 1916 it cost 18s. 6d. a pound. As a consequence of the publication of a report showing how useful wild white clover had been in restoring fertility to a farm on the Downs in Sussex, the price rose to 22s. in 1918, and reached a maximum of 35s. a pound in 1920. Larger supplies are available now than during the war and post-war days, and the price per pound in 1937 was about 6s.

From the foregoing it is clear that the present-day farmer has at his disposal a number of pasture plants much better than those available to his father or grandfather. But agricultural science has not only provided better raw material in the shape of grasses and clovers; it has demonstrated by experiments in all parts of the country how these plants may be controlled and made to yield the maximum amount of fodder.

Let us take seed mixtures first. Little need be said about the ordinary ley destined to yield for twelve months only. No revolutionary changes have been made in the one-year seeds mixture as the result of recent scientific investigation. Perennial rye grass, Italian rye grass, red clover, and alsike clover are still the most important plants used for one-year leys over large areas. For hay it has been shown that perennial rye grass combined with a late-flowering red clover will give heavier yields than Italian rye grass and an early-flowering red clover. But because very many farmers wish to graze the ley as soon as the nurse crop of oats or barley has been removed in late summer, the two latter species are often included.

In fact, so far as weight of hay from the one-year ley is concerned, we are probably little better off than were farmers two hundred years ago. Red clover sown alone will, in a good year, give better results than a mixture of clover and rye grass. But since every year is not a good year for red clover, it is generally considered more prudent to include some rye grass. Alsike clover can be used as well as red clover. Recommendations for a one-year seeds ley are very numerous; usually about 14 pounds of rye grass and from 4–6 pounds of red clover seed per acre are considered sufficient. If alsike clover is favoured, from 1–2 pounds per acre of this much smaller seed are included.

In the case of seeds mixtures for long leys and permanent pasture, however, very considerable changes have taken place during the last two decades—the general tendency being towards simplification. The older seeds mixtures were complex ones, and were made up of the seeds of a dozen or more species of pasture plants. There might be eight or ten grass species, and four or more species of leguminous plants. There might be one pound per acre or even less of the seed of some of the species. The ideas behind the complex seeds mixture were chiefly these. It was thought that by the inclusion of a large number of species the "take" or establishment of the pasture would be more certain than with a smaller number of species, since some at least of the different plants would find conditions to their liking. It was thought, too, that grasses vary considerably in their nutritive value, and that variety was a good thing. Above all, it was thought that by including in the same mixture plants which start growing early in spring and plants which develop late in the season, the pasture would be made productive right throughout the year.

Recent investigations have shown that these premises are unsound. Analyses show that the commonly used grasses do not differ very much in their nutritive value, but that each species has very different nutritive values at different stages of growth. The younger the grass the more nutritious it is. Management is as important as variety or species in obtaining young succulent fodder throughout the season. Also, it has been demonstrated that certain species of grass, sown in small amounts, are unable to establish themselves in competition with other, quicker growing and more vigorous, species. It has been shown, too, that of the species sown in a complex seeds mixture for permanent grassland, only about six or eight at the most are likely to survive in any appreciable amount by the time the turf is five or six years old.

As an example of a simple seeds mixture for general purposes over a long period of years, the Cockle Park mixture sponsored by Gilchrist is set out below :

Perennial rye grass, 16 lb. per acre ; Cocksfoot (chiefly New Zealand), 10 lb. ; Timothy (preferably Scotch), 4 lb. ; late-flowering red clover, 4 lb. ; Trefoil, 1 lb. ; wild white clover, 1–4 lb.

Only six species are included in this mixture, but with the exception of trefoil the rate of seeding is heavy.

Even simpler mixtures have given good results in various parts of the country, for it has been found that a combination of 12–16 lb. perennial rye grass and 2–4 lb. wild white clover per acre will often give rise to a very good turf without any additional species whatsoever. Usually, however, it is recommended to include a few pounds of either rough-stalked meadow grass, crested dogstail, or Chewings fescue. On dry soils it is better to reduce the rye grass and substitute cocksfoot.

There is not much difference in the cost per acre of simple and complex types of mixture, but as has already been stated, the simple mixtures generally give better results. This is due very largely to a better understanding of the value of perennial rye grass used in conjunction with wild white clover, but also to improved knowledge of the interaction of the various species.

By the use of properly compounded simple seeds mixtures, a good close turf can be established very much more rapidly and certainly than at any period of British farming. This is a fact that is bound to have profound results when its implications have become known to the general body of farmers, and, it must be added, to land owners as well.

It is still held by those who are not well acquainted with the results of modern grassland experiments that every permanent pasture goes through three well defined stages of existence. First of all there is a period of luxuriance for two or three years whilst short-lived grasses and clovers predominate. Then comes a period of poverty lasting from three to four, or up to ten years, during which the permanent grasses are slowly developing, followed by a third stage characterized by a " rich velvety covering of perennial rye grass and white clover characteristic of our best pastures." It was, and still is, thought that a good turf could not be established in less than twenty years.

This view is now very much out of date. It has been conclusively shown by innumerable experiments and demonstrations in all parts of the country that on all but the most unsuitable soils it is possible to get a good turf in two or three seasons, or even less—provided a suitable seeds mixture, including about one pound of wild white clover be sown, the soil be properly manured, and the grass be managed in the right manner.

To get these quick results the seeds should not be sown in a cereal crop. For a one-year ley the farmer is compelled to sow the seeds in the spring-sown cereal —oats or barley usually—in order to save time. But in the case of a permanent pasture there is no such necessity. What counts most is the turf itself. The value of a " nurse " crop has in the past been very much overrated. The cereal may protect the young grass and clover seeds from a hot sun, but in many ways it is extremely detrimental to them, cutting out light and air and competing with their roots. It is also very difficult to get the soil on which the cereal is growing into that fine state which grass seeds need for really good germination and establishment.

The modern way is, therefore, to put in the grass seeds either without any nurse crop at all, or with a few pounds of rape seed or Italian rye grass to give some protection in the very early stages. About six or eight weeks after sowing the seedlings can be lightly grazed. By doing this the livestock not only consolidate the soil, but also begin the process of distributing " stock nitrogen " in their urine, which has been found so beneficial to a turf. In an incredibly short time—a few months only in some cases—the wild white clover knits together the grasses into a turf which need never show signs of poverty under proper management.

Another thing which has been re-emphasized by recent experiments is this, that livestock, properly managed, are as essential to the maintenance of good grassland as are fertilizers. The good grazier has always realized this, but the point has recently been driven home by a series of experiments carried out by Martin Jones at Jealotts Hill, in Berkshire. It was found possible to change the botanical nature of a turf by managing the grazing in different ways. By heavy grazing in spring wild white clover could be greatly encouraged, and conversely, by allowing the grasses to grow long, the clover could be much reduced. By grazing just when any particular grass came into vigorous growth this species could, in the space of a year or two, be almost exterminated. A turf composed of perennial rye grass, cocksfoot, rough stalked meadow grass, and wild white clover could at will be so altered by management as to become chiefly rye grass, chiefly cocksfoot, or chiefly wild white clover.

To sum up this chapter, then, we may say that the modern farmer has at his disposal not only better perennial rye grass, cocksfoot, timothy, red clover, and wild white clover, but also better and more precise information regarding simple seeds mixtures and how to sow them so as to get rapid results; and he understands more fully how to manage his grazing to get the results he desires.

COLLATERAL READING

Those wishing to obtain information about individual grasses should consult *British Grasses and their employment in Agriculture*, by Armstrong (Cambridge University Press, 1937). Clovers and allied plants are described by Robinson in *Leguminous Forage Plants* (Edward Arnold and Co., 1937). A good and easily readable account of the different types of grassland in this country is given by Stapledon and Hanley in *Grassland: its Management and Improvement* (Oxford University Press, 1927). *White Clover*, by Ware (Ministry of Agriculture and Fisheries Miscellaneous Publications No. 46, 1925), gives an historical account of the plant and traces its rise in the estimation of farmers. Stapledon's *The Land: now and to-morrow* (Faber and Faber, 1936) should not be left unread by those who are prepared to think about grassland as a national asset. There are several good articles on grassland in Baillière's *Encyclopædia of Scientific Agriculture* (1931).

CHAPTER V

BREEDING AND FEEDING FARM ANIMALS

DURING the last 200 years farm animals have been greatly improved; how great has been the improvement can best be realized by comparing a photograph of a modern Southdown with an old picture of a sheep of 1700; or a photograph of an Angus heifer with a picture of the beef cattle of two centuries ago.

The improvement of livestock started with the work of Robert Bakewell about 1750. Bakewell had a genius for selecting sires and dams, and once he had discovered a suitable combination he was in the habit of practising "in-breeding," that is, mating father to daughter or brother to sister, to obtain his desired result and "fix the type." He also made a habit of hiring out sires to his neighbours; he was able to observe the type of animals they got, and if they proved useful he would use the sires again in his own breeding herds. In a relatively few years Bakewell was able to transform the huge, heavily-boned, badly-fleshed, slow maturing animals of his early days into smaller, finer-boned stock of better appearance, quicker maturity, and better quality. Other breeders followed his methods, and soon the best British breeds became superior to any others in the world.

Very little science, in the ordinary sense of the word, went into this remarkable improvement of livestock.

The livestock breeder was, and still is, much more of an artist than a scientist. He was able to obtain good results without being able to explain how and why, whereas a scientist not only wishes to get results, but wants the explanation as well. So far, science cannot give the stock breeder much assistance.

One of the reasons for this is the comparatively small amount of experimental work carried out in the breeding of farm animals : small, that is, compared with the work done in breeding plants. Farm animals are slow to breed, and often several years must elapse between the mating of a pair of animals and the arrival of the offspring at a sufficiently mature stage to permit of deductions being drawn. Animals, too, unlike farm plants, cannot be self-fertilized, and this leads to complications not experienced in the breeding of many farm plants.

When Mendel's principles of heredity were rediscovered, as described in a previous chapter, it was hoped that animal breeding would become a much simpler and more scientific proceeding. Some quite early experiments established the fact that certain characters—such as the presence or absence of horns in some breeds of cattle and sheep, the colour of the coat in cattle and rabbits, the comb character of poultry—behave as Mendelian units, and are inherited in accordance with Mendelian laws. But the number of characters of economic value so far analysed by breeding experiments is very small, because of the cost and the time involved. Numerous analyses have been made of certain characters belonging to small animals such as mice, rats, and rabbits, which breed much faster than cattle, sheep, or pigs, and information is slowly accumulating ; but it is not safe to say that because a character in, say, a mouse, is inherited in such and such a way, an apparently similar character in cattle will behave likewise.

One important and economically valuable piece of information has, however, been brought to light as the result of applying the Mendelian hypothesis to the breeding of poultry. It is the phenomenon usually referred to as " sex-linkage." The average poultry farmer is not able to tell the sex of a chick at hatching time. The egg farmer is therefore unable to pick out his future laying hens from the cockerels until several weeks have elapsed. This is a serious inconvenience, because he has to feed and house both the cockerels and the pullets until such time as the distinction can be made with certainty. Since the cockerels are of no use to him, food and time spent upon them are wasted. During the last year or two it has been found possible to distinguish between male and female day-old chicks by a careful study of minute differences in the vent, and expert workers are now able to " sex " young chicks very rapidly and very accurately. Poultry keepers as a rule do not possess the knowledge and experience which make possible this separation of pullets from cockerels in the day-old condition. Assistance was forthcoming, however, when Punnett at Cambridge discovered that in some breeds of poultry the colour of the plumage is, as it were, linked up with sex. He found, for example, that if a cockerel of a breed having plumage of a buff or golden-brown shade (a " gold " cockerel) is mated with a hen of a breed with creamy-silver plumage (a "silver" hen) the cockerels will have silvery plumage and the pullets will have golden plumage. These differences are visible in the plumage of newly hatched chickens ; all the silvery-white chickens can be safely destroyed at once in the knowledge that they are cockerels and worthless for egg production.

Nor is this sex-linked crossing confined to the "silver" and "gold" breeds of poultry. A black cockerel mated with a hen having "barred" plumage, such as the Plymouth Rock, will throw cockerels which are "barred," and pullets which are black. At hatching, the male chickens can be detected by a whitish patch on the back of the head, because the pullets are completely black.

It is important to note that the mating must be made in the manner specified. The distinguishing character is carried by the hen, and is transmitted to her male offspring only. The silver hen transmits the silver plumage to her sons alone. If the cross is made the other way round, and a silver cock is mated with a golden hen, then equal numbers of gold cockerels and gold pullets, and silver cockerels and silver pullets are produced. There is in this cross no sex-linkage of plumage colour.

The offspring of a sex-linked cross cannot be used for stock purposes, because the plumage colour is associated with the wrong sex. To overcome this disadvantage Punnett evolved a breed called the Cambar, which is sex-linked within itself. It was derived from a cross between a Barred Plymouth Rock and a Gold Campine. The pullets are dark brown, the cockerels pale grey, striped with brown. More recently still he has evolved the Legbar breed, derived from a Brown Leghorn-Barred Rock cross.

Whilst science has provided no short cuts to the successful breeding of farm animals, it is helping to direct attention to points of immediate commercial importance as opposed to merely show-points. The milk yields of many breeds of cows have been considerably improved since the beginning of milk recording. In the most complete schemes for milk recording the weight of milk given each day by each cow in a herd is put down on a sheet, and at the end of the lactation period the amounts are totalled. This provides essential information for the breeder, because, acting on the principle that like tends to beget like, he uses only the higher yielding cows for breeding purposes. Of course it is not possible to obtain information about a bull in this way, but in the first place he would naturally be selected from a deep milking strain. The milk yields of his daughters would provide evidence as to his powers of transmitting this quality, and when " proven " in this way he can be used in confidence.

In a similar way pig recording schemes are providing information which it is hoped will be of increasing value. Two things are of prime importance in pig raising—namely, the number of piglings that a sow can bring forth and rear, and the amount of meat that the pigs can put on for every pound of food eaten. The pig recording societies aim at providing this information by weighing and counting the litters at weaning, and by weighing and measuring the carcasses of the marketable pigs. In this way it is possible to discover those strains which are the most profitable to the farmer, and they can be used for breeding. At the same time the less profitable strains can, and should, be discarded ; it appears that, in this country, the problem of general improvement in the pig industry is more a matter of eliminating the poor breeding pig than raising the standard of our best breeds. Recording provides the figures upon which the separation into good and not so good can be based.

A scientific development in animal breeding which may have a very profound influence is artificial insemination. This involves the collection of sperm from a sire, and its artificial introduction into the breeding passage of the female. The technique of the operations involved is still in process of development, but animals born as a result of artificial insemination are quite normal, and there are no harmful results either to their dams or to their progeny. If the artificial insemination of farm animals can be proved to be a practical proposition (at the moment the process is in its infancy) it is clear that the use of good sires can be greatly extended, since the transportation of a small vessel of sperm is much less difficult and less likely to spread disease than the travelling of a stallion or the bringing of cows to a pedigree bull.

The scientist in the present state of his knowledge may not be able to give the animal breeder a great deal of assistance, but in the feeding of livestock very great advances have been made during recent years as the result of scientific investigations.

Before a scientist can give sound advice to a farmer who wishes to know how to feed his animals efficiently and economically, the scientist himself must know something about the following points:

1. The chemical composition of the feeding stuffs to be used.
2. The digestibility of these foods.
3. The chemical composition of farm animals.
4. The way in which the digested constituents of the food behave after they pass into the blood and are carried to the various parts of the body.

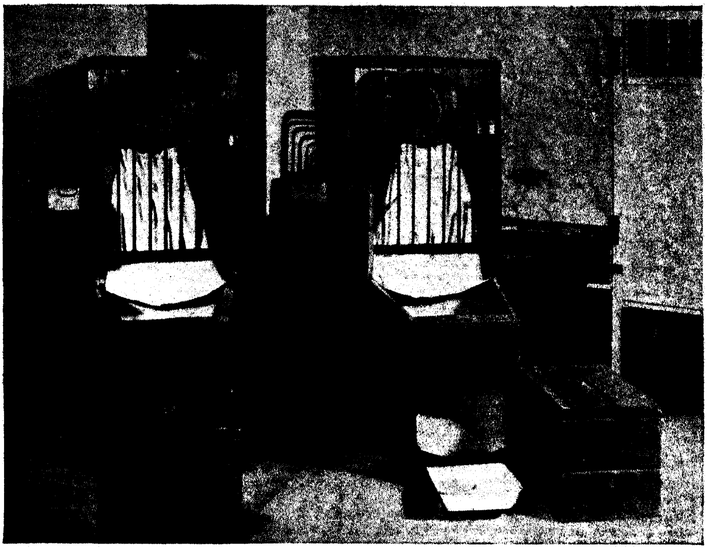
The first point is a comparatively simple one, though, of course, improvements are always being made in analytical methods so that fresh information is continually coming to light. The early analysts soon decided that the four main constituents of animal food-stuffs are: (*a*) Carbohydrates, such as starches and sugars; (*b*) Proteins, which are important largely because of the nitrogen they contain; (*c*) Fats or oils; (*d*) Mineral matter. Modern chemists have not found it necessary to challenge these conclusions; rather they have amplified and strengthened the views of their predecessors. Thus they have proved that the different proteins, fats, and carbohydrates vary in nutritive value, this being especially the case with the proteins. More important still, they have demonstrated that the four classes of ingredients mentioned above, although they form by far the greatest part of the food, may fail to act properly unless the food also contains small quantities of other ingredients, such as the vitamins.

When the bodies of farm animals are analysed it is found that the flesh and muscles consist very largely of protein, together with a certain amount of fat. The amount of carbohydrate is very small, and can usually be neglected so far as feeding problems are concerned. There is relatively more protein and less fat in a young, growing animal than there is in an older one. The bones are found to contain a large amount of mineral matter, especially calcium and phosphorus.

One of the first problems to confront the worker on animal nutrition was that of finding out how the proteins and fat of the animal are formed from the constituents of the digested food. The early workers had to ask themselves these principal questions: is animal protein formed entirely from vegetable protein? is animal fat formed entirely from vegetable oils? or can the carbohydrates and protein also contribute to their manufacture? The first question was not difficult to answer, and one can say with practical certainty that animal protein can only come from protein in the food.

The second question was more difficult to investigate, and the answer was only finally obtained by using a device known as a "respiration chamber," designed by a German called Pettenkofer. This was a "box" sufficiently large to accommodate a farm animal, and it had openings through which food could be passed and dung removed. Air was drawn in by means of a fan after it had been measured and analysed. The gases given off by the animal were drawn off into a container, measured, and analysed. By means of this box it was also possible to feed a ration containing a known quantity of nitrogen and carbon, and by subtracting the quantity of carbon dioxide in the air entering the chamber from the quantity in the air leaving the chamber, the amount of carbon dioxide expelled by the animal could be estimated. The amounts of nitrogen and carbon retained in the animal's body could be found by subtracting the amounts of these elements in the dung and urine from the amounts supplied in the food. By simple calculations the weight of protein and fat formed in the body could then be ascertained. As the result of numerous experiments over a number of years it became known that fat could be formed from all three ingredients of a food—protein, fat, and carbohydrate.

The foundations of modern livestock rationing were laid, however, when Gustuv Kühn, in Germany, decided in the 1890's to investigate the amount of energy



Apparatus for determining the digestibility of foodstuffs.

The method of collecting the droppings from the sheep is clearly shown.

(*By permission of Dr. H. E. Woodman, Cambridge.*)

required by bullocks when neither losing nor gaining weight. His work was carried on by Kellner, upon whose work is based much of the existing theory and practice of rationing.

The energy present in a food can be measured by the amount of heat it gives out when completely consumed. The energy in the digested food is utilized by an animal either for the purposes of work or for the production of heat, or is stored up in the body as fat or other tissue. The energy in the undigested part of the food cannot be used by the animal, but it can, of course, be estimated by examining the composition of the dung and of the gases (chiefly marsh gas and carbon dioxide) expelled from the intestines and lungs.

The energy present in food is estimated by an apparatus called a calorimeter. In essentials it is a small closed vessel, usually called a bomb, made of metal, placed inside another vessel containing a known weight of water. The whole apparatus is covered with insulating material to prevent heat escaping. One gramme of the food to be tested, together with enough oxygen to ensure complete combustion, is put in the bomb, and fired by an electric spark. The heat given off during combustion is taken up by the water, the temperature of which is indicated by a thermometer. If the gramme of food thus fired raises the temperature of a gramme of water one degree centigrade, the energy value (*i.e.* the heat-producing capacity) of the gramme is said to be one calorie. A pound of the same material would have an energy value of 453 calories (1 lb. = 453 grammes). This explanation is necessary, because Kellner used calories when calculating the maintenance and fat production requirements of the animals he had under test.

The first thing Kellner desired to find out was how much food a bullock requires when neither gaining nor losing weight, that is, neither storing up fat or flesh nor losing it. Breathing, feeding, digesting, standing still, are all operations which require energy, and the food necessary to supply these needs is termed the maintenance requirement. Kellner put a 12-cwt. bullock in his respiration chamber and fed it on hay or straw in such amounts that, so far as could be judged, the animal's weight either remained stationary or showed a slight increase. The calories supplied in the food were known, and the calories in the various excreted substances were determined. The difference between these two totals gave the number of calories required for maintenance. Of course it was impossible to devise a ration so as to get absolutely no change in bodyweight, but adjustments could be made if, as a result of examining the figures for carbon and nitrogen in the gases, urine, and dung, it was found that small amounts of fat or flesh were being added to, or removed from, the body.[1] Kellner found that a 12-cwt. bullock needs about 15½ lb. of meadow hay (31,000 calories) per day for maintenance, and a 9-cwt. bullock about 14 lb. per day.

Next, the bullock was fed a maintenance ration, but to this was added a definite weight of starch of known digestibility. By calculation, the amount of fat formed in the body by this extra carbohydrate was determined. It was found that for every 4 lb. of digestible starch eaten, over and above a maintenance ration, 1 lb. of fat was stored up in the body.

In a further experiment a known amount of linseed cake was fed in addition to the maintenance ration, but the amount of fat produced by 4 lb. of linseed cake was slightly less than ¾ lb. As a producer of fat, linseed cake is obviously only about three-quarters as efficient as pure, digestible starch. If the value of the starch as a fat producer be put at 100, that for linseed cake is 74. This last figure is called the Starch Equivalent of linseed cake. It means that if 100 lb. of linseed cake are fed to a fattening bullock, *in conjunction with a maintenance ration*, it will lead to the production of as much fat as 74 lb. of digestible starch fed in similar circumstances.

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[1] For methods of calculation, see pp. 49–64 of James Wilson's *Principles of Stockfeeding.*

By repeating the experiment with other common feeding stuffs, their starch equivalents were determined. Thus the starch equivalent per 100 lb. of bran is 42, of maize meal 81, of dried sugar beet pulp 65, of oat straw 20, of cabbages 6.6, and so on.

Kellner found, too, that the different constituents of feeding stuffs, fed together in a mixture, behaved as a rule in the same ways as they do when fed separately. Four pounds of starch plus 4 lb. of linseed cake store up 1¾ lb. of fat. But if there is much fibre present, as in straw and hay, the fat-producing value of the constituents is reduced. This is because the animal has to do more internal work in digesting the fibre, and in searching out, as it were, the digestible from the indigestible material.

Now these experiments were extremely valuable. They showed that fat may be derived from the protein, fat, or carbohydrate in the food—a controversial point since the early days of Liebig's writings. They demonstrated that a definite, calculable amount of food is needed to keep an animal of a definite weight alive at a constant weight. And they showed, above all, that it is possible to predict from an analysis of a food how much fat an animal may be expected to lay on if fed with a definite amount.

To be able to calculate the fat-producing possibilities of a feeding stuff, Kellner conducted further experiments. He made comparisons of the fat-producing values of pure digestible protein, digestible oil, digestible starch, and digestible fibre. He found that 1 lb. of digestible protein is equivalent in fat-producing capacity to 0.94 lb. digestible starch; 1 lb. of the digestible oil of oil cakes is equivalent to 2.4 lb. digestible starch; 1 lb. of digestible oil from cereals and leguminous seeds is equivalent to 2.12 lb.; and 1 lb. of digestible oil from coarse fodders and roots is equivalent to 1.9 lb. digestible starch. In ruminant animals digestible starch and digestible fibre are of the same value for fat production.

To estimate the starch equivalent per 100 lb. of any food-stuff, therefore, it is only necessary to perform the following calculation:

Percentage digestible protein × 0.94
,, ,, oil × (2.4 or 2.1 or 1.9)
,, ,, fibre
,, ,, carbohydrate

Sum total = starch equivalent

Nowadays it is necessary to multiply the starch equivalent figure thus obtained by a factor V. This modification has been found necessary for the following reason: Kellner made use of pure nutrients when he made his experiments, but in ordinary practice the nutrients are not in this condition, and they are intimately mixed up with the indigestible part of the ration. If linseed cake, for example, be fed in the ordinary state it will produce only 97 per cent. of the amount of fat theoretically possible. The factor V for linseed cake is therefore $\frac{97}{100}$, and the figure for the starch equivalent obtained by the method just described must be multiplied by 0.97.

Tables are available giving the average percentage composition of all the feeding stuffs likely to be used on the farm. Both the crude and the digestible nutrients are set out, together with the starch equivalent and the value of V. From these figures it is possible to compare the values of different feeding stuffs for the production of growth, fat, work, and so on.

The figures provided in such tables are not of academic interest only. They can, and should, save the farmer money. At the same time, however, it must be remembered that the figures are only approximate. They are the best available, but no one who understands the way in which they have been obtained claims that they are absolutely accurate. They serve as the best available guide, but to work out rations based upon them to two places of decimals is ridiculous.

Starch equivalents can be utilized by a farmer who wishes to know which of two feeding stuffs offers the better value at current prices. Let us take linseed cake and decorticated cotton seed cake. (A decorticated material is one from which the outer husk has been removed.) First of all we have to remember that a feeding stuff is not completely utilized by the animals to which it is fed. The undigested portion goes into the manure, and has a fertilizing value. Normally this manurial value is recouped by the farmer in a subsequent crop. In the last year of a tenancy, however, the residual manurial worth of all feeding stuffs has an immediate value to the outgoing farmer, and the incoming tenant pays cash for it on a recognized scale. Therefore, in assessing the value of a feeding stuff as a food it is necessary first of all to deduct the value of that part which cannot feed the animal, that is, its manurial value.

Every month the manurial value per ton of the various food-stuffs is published in the *Journal* of the Ministry of Agriculture ; the farmer does not have to calculate them, but this is how it is done. It is assumed, as the result of numerous experiments, that $\frac{2}{5}$ of the total nitrogen of the food escapes from the animal into the manure, $\frac{3}{4}$ of the phosphoric acid and $\frac{3}{4}$ of the potash. Now these three fertilizing ingredients can be purchased in the form of concentrated fertilizers. For example, in February 1938, sulphate of ammonia containing 20.6 per cent. of nitrogen was costing £7, 12s. 6d. per ton ; dividing the percentage of nitrogen into the cost per ton gives us the unit price of nitrogen at this date, namely, 7s. 6d. In a similar way the unit prices of phosphoric acid and potash may be arrived at. They were, at the time stated, phosphoric acid 2s. 7d., potash 3s. 8d. The manurial value of a food at any given time is found by adding together :

$\frac{2}{5}$ percentage nitrogen × unit price of nitrogen.
$\frac{3}{4}$ „ phosphoric acid × unit price of phosphoric acid.
$\frac{3}{4}$ „ potash × unit price of potash.

In February 1938 this was, for linseed cake £1, 1s. per ton, for decorticated cotton seed cake, £1, 10s. per ton.

It must again be emphasized that the farmer does not have to perform these elaborate calculations. The information is supplied to him regularly in various journals and newspapers.

To compare the relative values of linseed and cotton seed cake as food stuffs, then, we first deduct the manurial values. Linseed cake at £11 per ton has a feeding value of £11 minus its manurial value (£1, 1s.)=£9, 19s. It is now necessary to discover the cost per unit of starch equivalent, and this is done by dividing the feeding cost per ton (*i.e.* total cost minus manurial value) by the starch equivalent. Reference to published tables[1] shows that the starch equivalent of linseed cake is 74. The cost per unit of starch equivalent in linseed cake is £9, 19s.÷74, or 2s. 8d. The cost per pound of starch equivalent is $\frac{\text{2s. 8d.}}{22.4}$=1.43d. (22.4=1 per cent. of 2,240 lb., or 1 ton). Decorticated cotton seed cake costing £8 per ton has a food value of £8 minus its manurial value, £1, 10s., or £6, 10s. per ton. Its starch equivalent per 100 lb. is 68.4. The cost per unit of starch equivalent is £6, 10s.÷68.4 =1s. 10d. The cost per pound of starch equivalent is $\frac{\text{1s. 10d.}}{22.4}$=1.0d.

Consequently, at the prices ruling, decorticated cotton seed cake is the better value, provided of course that it is suitable for the class of stock for which it is intended.

Kellner's starch equivalent method is now accepted as being the best available means of indicating the productive, or energy, value of a feeding stuff. Its great merit is that it gives, by means of a single figure, the information about a food-stuff required by a stock feeder. Before the introduction of starch equivalents it was a very difficult matter to decide what was the practical value of the information provided by a chemical analysis.

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[1] *Rations for Livestock*, Bulletin 48 of the Ministry of Agriculture.

Kellner's work made it possible to summarize, in one figure, the information hidden in the analytical data.

It should be mentioned here that Armsby, in America, was investigating the problem of animal nutrition at about the same time as Kellner, and that, on the whole, his results agreed very fairly with those of Kellner's. Armsby used a respiration calorimeter for his experiments. He put the animal in a specially designed apparatus and measured the heat given off by the animal to find out how much utilizable energy his rations contained.

The starch equivalent method was sponsored in this country by Charles Crowther about 1905. At first its implications and value were not appreciated, but from about 1911 onwards it began to be used more freely, until now it is the basis upon which most of the scientific rationing in the country is based.

Kellner worked with three- or four-year-old bullocks, but it has been found since that his conclusions as to the comparative values of foods apply quite well to the fattening of other full-grown animals such as the sheep and pig, and also to the requirements of the working horse. His conclusions are not so accurate where active growth, or the production of milk and eggs, are concerned. Special tables have been prepared for modifying Kellner's figures for these special purposes, but are not yet in general use.

More recent investigations have shown, too, that the various proteins differ widely in their value for food purposes. The proteins of the cereals are not so valuable as those of the leguminous seeds, for example. The conclusion to be drawn from this is that proteins of several different sorts should be included when a ration is compounded.

It is not possible to describe exactly how rations for stock are devised, because each class of animal has different requirements. In devising the ration, three main points require attention. First, the live weight of the animal, for upon this depends the quantity of food necessary for maintenance. Second, the purpose for which the animal is being fed, such as work, fattening, milk production, etc. (the food necessary for this is called the production ration). Third, the capacity of the animal for food consumption ; obviously it is no use giving an animal more than it will eat. In deciding upon the actual food to be employed, the points to be looked after are these : the starch equivalent, the amount of digestible protein, the mineral content, and the vitamin content. The importance of minerals in a diet has only recently been rediscovered. Liebig, about the middle of last century, strongly emphasized the need for minerals in animal feeding, but for many years this side of rationing was ignored. Now it is realized that starch equivalent and digestible protein alone do not constitute an ideal food, especially for young animals and milking cows. Both minerals and vitamins, and probably other substances as well, are necessary. It is therefore absurd—and this applies to human nutrition—to look for the solution of nutritional problems in the supply of one particular constituent of the diet. To emphasize the importance of an ample supply of vitamins whilst neglecting the proteins cannot but lead to protein starvation, which is just as disastrous to health as vitamin starvation. Balance in a diet is essential to health and growth.

The habit of adding a mineral supplement to a scientifically compounded ration is consequently becoming very common. The supplement is usually composed of approximately equal parts of salt, sterilized feeding bone flour, and finely ground chalk. Two to three pounds of this mixture are mingled with one hundredweight of the concentrated food.

The new knowledge that has been gained about foods and feeding during the last thirty years has undoubtedly enabled farmers to ration their animals more efficiently and more cheaply. In the case of fattening animals it has led to a reduction in the use of oil cakes such as linseed and cotton seed cakes. These were formerly fed to the fattening animals in enormous amounts, with two ideas in mind. It was thought that oil and protein formed much fat in the animal and that the undigested food would greatly enrich the manure. Now it is known that protein is a very poor and expensive producer of fat, for only about 30–40 per cent. of its energy value can be stored as fat, and protein is very dear to buy. It is now known, too, that although cake feeding does increase the manurial value of dung, it does so in a very extravagant manner. It is cheaper to buy extra chemical fertilizers than to try to add the manurial ingredients to the soil through dung by extra rich feeding.

In the case of rationing for milk production there have been considerable developments since the war. Economical rationing in a dairy herd can only be accomplished if the yield of each cow is known, hence rationing is linked up with milk recording (p. 81). The ideas behind the rationing of dairy cows are these: first, to feed a maintenance ration; second, to feed a production ration according to the yield of milk; third, to control the bulk of the ration so as not to overload the stomach and interfere with digestion. The last point, control of bulk, has received much publicity lately, and it is undoubtedly very important. The assumption now made is that the total daily consumption of dry matter for a 10-cwt. cow should not exceed about 30 lb. For a cow giving up to 4 gallons of milk daily, 20 lb. of hay are required for maintenance. To produce 1 gallon of milk, 3½ lb. of concentrates ("cake") are needed. The 4-gallon cow thus gets 20 lb. hay, plus 14 lb. concentrates, daily. A 5-gallon cow would get, theoretically, 16 lb. hay and 17½ lb. concentrates; but in the case of extremely high-yielding cows, the amount of hay fed as a maintenance ration may have to be reduced, in order to keep the bulkiness of the whole ration within the capacity of the cow's stomach. The concentrated food would be a mixture compounded in accordance with the starch equivalents and market prices of the various feeding stuffs available.

Collateral Reading

A simple account of animal breeding is given in *Crop and Stock Improvement*, by A. B. Bruce and H. Hunter (Ernest Benn, 1926), and in *The Cattle-breeder's Handbook*, by J. A. Scott Watson, James Cameron, and G. H. Garrad (Ernest Benn, 1926). *The Breeding and Feeding of Farm Stock*, by James Wilson (Methuen, 1921), is also worth reading on account of its simplicity and its illustrations. More technical information is provided in *Animal Genetics—an Introduction to the Science of Animal Breeding*, by F. A. E. Crew (Oliver and Boyd, 1925).

An easily understandable account of the development of the science of animal nutrition is given in the opening chapters of *The Principles of Stockfeeding*, by James Wilson (Vinton, 1927), whilst practical information is contained in *Rations for Livestock*, by H. E. Woodman (Bulletin No. 48, Ministry of Agriculture, 1936). See also *The Feeding of Dairy Cows*, by J. Mackintosh (Bulletin No. 42, 1936).

CHAPTER VI

THE FIGHT AGAINST FARM PESTS

The big-game hunter is much more likely to suffer injury or death from insects than from the big mammals which are his quarry. Civilization is indeed a continuous fight against all sorts of insect enemies, and the farmer, no less than the tropical engineer or medical officer of health, has to spend a great deal of his time considering how to outwit and destroy his tiny six-legged opponents.

In this chapter the case of the general farmer only will be considered. The fruit farmer and the horticulturist have to contend with many more insects and allied pests than the mixed farmer, largely because their industries are so intensive and because each individual plant has a greater value than is the case on a general farm. Only a specialist can hope to have a knowledge of all the very numerous insects likely to attack fruit trees and garden and glass-house crops. Large sums of money have to be spent every year on chemical spray fluids and fumigants to combat these pests, but on the general farm the position is perhaps not quite so serious. Certainly the general farmer cannot afford to spend as much on these substances as the horticulturist.

It is very difficult to obtain a reliable estimate of the losses caused by insect damage to farm crops and live stock. The partial or complete failure of a crop may be due partly to insect attack, partly to fungus diseases, partly to weather and cultural conditions ; to assess the damage brought about by each of these is an impossible task. For these and other reasons it is more or less pure guesswork to state a figure for the losses caused to agriculture by insect pests. The figure of £6,000,000 annually has been mentioned as the cost of insect damage to crops alone in this country, taking no account of damage to live stock, timber, and stored products. This is a sufficiently large figure to command attention, even in these days of astronomical national budgets, for it is equivalent to about 2d. on the income tax. It should serve as a justification for this chapter.

Most of the small creatures included in the term " pest " are insects. In the correct sense of the term an insect is a creature belonging to the Order Hexapoda or Insecta, having three pairs of legs in the adult state, a body divided into three parts, and usually having wings. This definition would exclude animals such as spiders, mites, ticks, millipedes, slugs, snails, and eelworms; but all these creatures are the concern of the agricultural entomologist, and for our purpose can be classed as insects.

In what ways has science assisted the farmer to overcome his insect enemies ? Actually it is just about 100 years since the careful study of agricultural insects really began. About 1840 John Curtis began writing articles on insect pests in the Journal of the Royal Agricultural Society, and in 1859 he published a book on *Farm Insects* which is still regarded as a standard work. Then from 1881 onwards, Miss Ormerod, one of the most indomitable women of her time, published at her own expense a Report on Injurious Insects every year for twenty-four years. These manuals, or pamphlets, gave the latest information about farm pests, and greatly stimulated investigations into their behaviour and control. Since the beginning of the present century the Government have assisted research into entomological problems of all descriptions, and dozens of workers in this country alone are investigating different aspects.

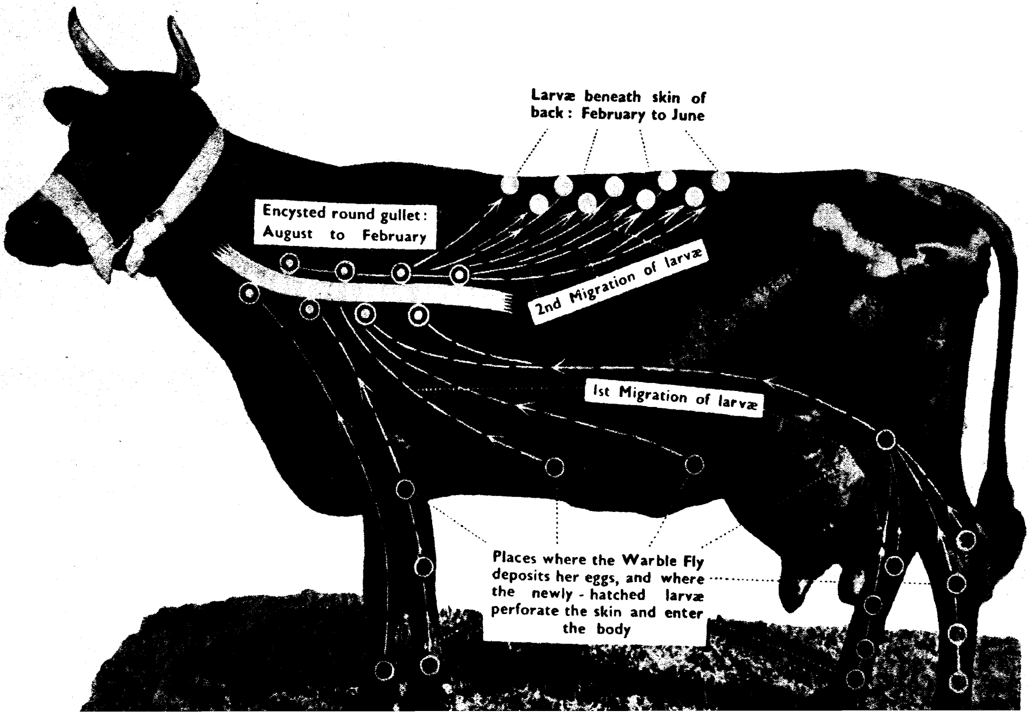
As a result, the farmer of to-day is better able to deal with most of his insect enemies than were his father and grandfather. Not with all of them, for the wireworm problem is not very much nearer solution than it was in the days of John Curtis. On the whole, however, the farmer benefits from two main developments in entomological work: first, the careful study of the life history of the pests, and second, the utilization of new chemical substances in destroying the insect during its most vulnerable stage of development.

To illustrate this contention we cannot take a better example than the Warble Fly. This is a large fly which could quite easily be mistaken for a bee. The larvae, or maggots, of this insect spend a large part of their life along the backs of cows and bullocks immediately beneath the skin. In spring, the presence of the grubs is made known by the swellings which arise over them. To obtain air the maggot, which is commonly called the "warble," pierces a hole right through the skin; when the cow or bullock is killed and the skin dressed, these breathing holes appear as perforations in the hide, with the result that the value of the leather is very much reduced. Warbled hides may fetch from one penny to threepence per pound less than first quality hides. Until recently the annual loss to the leather trade on account of warble fly damage in Great Britain amounted to about half a million pounds. The direct loss to farmers and graziers cannot be estimated, but it is well known that beasts infested with warbles are more restless and do not thrive so well as beasts which are warble-free, on acount of the irritation set up by the parasites.

Warbles have been a pest from time immemorial, but only recently has it been possible to control them. There are several reasons for this. In the first place, the true life history of the parasite has only recently been worked out. Early investigators, including a number of well-known scientists, made a false deduction right from the start, which led to considerable confusion and to recommendations which would have resulted in a great waste of time and energy on the part of farmers had they been extensively carried out. These investigators noticed the swelling warbles along either side of the spine of cattle, and immediately assumed that the warble fly laid her eggs on the backs of live stock. "If we can smear the backs of cattle with substances unpleasant to the female fly," they said, "we shall prevent egg-laying and solve the problem." So during the months when the fly was known to be on the wing, farmers were encouraged to cover the backs of their animals with all sorts of evil-smelling oils and ointments to act as deterrents. All these dressings were quite useless, but it was difficult to convince people of this until Carpenter's experiments during the three years 1904–7, and even now it is not easy to get the older farmers to appreciate this fact. Carpenter dressed 67 calves and kept with them 24 untreated calves. The average numbers of warbles per animal were: treated, 10, untreated 12. He treated the backs of 28 yearlings, and kept 11 untreated yearlings with them. The treated animals had an average of 24.5 warbles each, the untreated animals 27.6 warbles. This was sufficient proof that dressing the backs of cattle has no influence on warble fly attack.

Gradually new and accurate information about the habits of the warble fly was gathered together, until about 1916 an amazing life history became revealed. This is the behaviour of the warble fly, or rather flies, for there are two different species now known. The female is on the wing during the summer months, and sticks her eggs on to the hairs of cattle, either singly or in rows according to the species of fly. But the insect never lays eggs on the *backs* of cattle. Usually it is the lower parts of the legs which attract the flies, though sometimes eggs are stuck to hairs on the underside of the belly. It was on this point that the earlier workers went wrong. Obviously, if the fly has no interest in the backs of cattle it is waste of time trying to keep her off this region.

The eggs hatch in four or five days, and tiny maggots emerge, which at once crawl down the hair to which the eggs are attached, and burrow into the skin, and disappear. Where have they gone ? We do not know exactly how they get there, but several weeks later these maggots are to be found in the tissues of slaughtered cattle in the region of the gullet, that is, the tube leading from mouth to stomach. Possibly they make the long internal journey from the legs to the front of the body by getting into a blood vessel and being carried along in the blood. The maggots remain near the gullet for some weeks, even months, until they are about half an inch long, whereupon they make their way through the flesh of the beast, up along the ribs, to the back. They bore breathing holes through the skin and feed upon the inflamed flesh of the beast, until in the spring they



Larvæ beneath skin of back: February to June
Encysted round gullet: August to February
2nd Migration of larvæ
1st Migration of larvæ
Places where the Warble Fly deposits her eggs, and where the newly-hatched larvæ perforate the skin and enter the body

become full grown. They then wriggle out of the hide, fall to the ground, and pupate, that is, go into a resting stage. Six weeks later the fly emerges from the pupa.

This is an extraordinary life history, and it took a long time to work it out. The passage of the maggot from leg to gullet was so unexpected that special experiments were necessary to prove that the eggs were not licked off the hairs and transferred to the gullet via the mouth. The life history once established, however, it became obvious that the only way of fighting the pest is to kill the warbles before they escape from the backs of the cattle. Dressing the legs and bellies of animals with deterrents is not possible on the farm, since no effective deterrent is known and the practical difficulties are too great.

The warbles can be squeezed out in spring fairly easily, and such prematurely removed maggots do not form pupae. But to remove thirty or more warbles in this way from a single animal takes a lot of time, and in a large herd tremendous labour is involved. Also, it is necessary to examine animals more than once, because the maggots may be making their way to the back over a period of several weeks, and late arrivals might escape. For similar reasons, the injection of lethal substances into each warble with a hypodermic syringe is not a practical proposition on the farm, however efficient it may be under experimental conditions. Some cheap substance is required which can be easily brushed over the backs of cattle, killing the maggots but not harming the cattle.

All sorts of oils, sheep dips, tars, and so on were tried, but only tobacco-and-lime was found at all satisfactory, and there were objections to this. Now, round about 1920 chemists engaged upon entomological problems began to take a great interest in tuba-root, a tropical arrow poison, the main source of which is the root of a tropical plant called *Derris elliptica*, or Derris, which was found to be very deadly to insects. Mention has already been made of the very considerable lag between the discovery of a new principle and its application to farming, and here is an instance of a chemical discovery lying fallow for seventy years. It was suggested by Oxley as long ago as 1848 that tuba-root might be employed against insects; natives in Malay had long used tuba-root as a fish poison, and the Chinese had also employed it as an insecticide. But not until the second decade of the present century did the white races pay much attention to this, as we now know, remarkable plant.

Investigations in this and other countries soon showed that Derris possesses very valuable properties. It is relatively harmless to mammals, including man, but is very deadly to fish and insects. It kills insects both by contact and when taken into the stomach. The poisonous principle is called rotenone, and at first there was some difficulty in standardizing the rotenone content, with the result that preparations of Derris gave differing results at different times when used as insecticides. This substance attracted the attention of those working on the warble fly problem, and experiments carried out in various parts of the country, notably in Worcestershire and Scotland, between 1924 and 1931, showed that Derris powder combined with soft soap can kill warbles very cheaply, effectively, and without harming cattle, if properly applied to their backs at the proper time.

But a fresh problem now arose. A farmer might have the knowledge and materials necessary for the destruction of warbles in his cattle and dairy cows, but could he be induced to carry out the work if his neighbour neglected to do likewise? Warble flies do not travel great distances, but obviously flies hatched out on an infected farm might easily lay their eggs on cattle belonging to a neighbouring farmer who had spent a lot of time and trouble in clearing his own farm. It was realized that the warble fly would have to be regarded as a national problem.

Denmark anticipated us in this matter by several years. In 1922 it was estimated that 20.5 per cent. of the hides in that country were perforated with holes made by warbles. In 1923 the Danish Legislature introduced regulations compelling farmers to destroy warbles in their herds, with the result by 1924 the percentage of warbled hides dropped to 4.5 per cent.

In 1936 the Ministry of Agriculture and Fisheries issued the Warble Fly (Dressing of Cattle) Order, which requires all visibly infected cattle to be treated with a preparation compounded of 1½ ounces of derris resins (or ½ ounce of rotenone) and 4 ounces of soap. The treatment must begin between March 15 and March 22, or as soon after these dates as the maggots appear under the skin on the backs of cattle, and must be repeated at intervals of not less than 27 days nor more than 32 days as long as the maggots continue to appear. Alternatively, mechanical means (such as squeezing) may be employed to remove and effectively destroy all ripe maggots at such intervals, not exceeding 10 days, as may be necessary to prevent the escape of live maggots. Treatment by either of these two methods is not required after June 30th in any year.

The warble fly pest has been treated at this length because it illustrates very well how science is being brought to the aid of farming. First, there is the realization of the damage and failure of rule-of-thumb methods to cope with the pest. Second, there is the slow and painstaking study of the parasite and its method of living, a study in which many workers are engaged, each adding a few items of information which are slowly built up into a complete picture. Next come experiments to determine the best way of breaking the life cycle, usually involving co-operation with the experimental chemist; successful experimental methods have then to be simplified and recommended in such a way that they may be freely used under farming conditions—for these may differ very considerably from experimental conditions. Finally, in some cases, regulations have to be drawn up on a national scale to compel universal adoption of control measures, so that farmers who take the trouble to combat the pests do not have their work thrown away through the carelessness and selfishness of their neighbours.

A further instance of legislative control of an " insect " pest of farm stock is provided in the regulations dealing with sheep scab. Scab, or scabies, or mange is caused by various microscopic mites which live on, or just beneath, the skin of sheep and other farm animals. The irritation set up by the parasites causes a crust, or scab, to form over the mite, and allows the affected animal no rest. The wool drops out and the sheep may become so emaciated that it dies. Infection is spread by contact between healthy and contaminated animals, or through rubbing against posts and fences used by scabby sheep. When it was shown by scientific investigators that scab could be controlled by dipping infected sheep in solutions of certain chemicals, Parliament felt compelled, in the interests of farmers themselves, to make sheep-dipping compulsory throughout the country. At the same time, since conditions under which sheep are kept vary so much in different counties, the working of the regulations is left in the hands of local authorities.

Sheep dips contain various substances such as nicotine, carbolic acid, sulphur, or arsenic. A great deal of research has been conducted, both by commercial firms and official research workers, into the questions of dips, but so far nothing has been discovered which will kill the eggs of the scab mite without harming the sheep. That is why local authorities, in the case of an outbreak of sheep scab, compel the owner to dip his sheep twice. The first dipping kills the actual mites; investigation has shown that unhatched eggs are not destroyed, but develop about ten days later. The second dipping, which must take place not earlier than the eighth, and not later than the fourteenth day following the first dipping, kills the mites emerging from these eggs before the mites themselves are old enough to lay more eggs.

Although from a scientific point of view the control of sheep scab offers no insuperable difficulties, the disease is by no means stamped out in hilly districts where sheep roam in large flocks over wide areas. Natural difficulties and the human element have so far kept the disease alive in these areas.

In a minor way, new discoveries are assisting in the control of other insect parasites of farm stock. Poultry, for example, are frequently plagued with lice and fleas which, on account of the irritation they cause, may bring about considerable losses. The discovery of the insecticidal properties of derris powder and sodium fluoride has made it possible to destroy the parasites quite effectually, and these two substances have supplanted the old type of pyrethrum powder to a considerable extent. Modern pyrethrum powder, though, is quite an effective insecticide. The use of these powders, however, necessitates handling each fowl individually, and takes considerable time. Quite recently, preparations containing nicotine (the alkaloid present in tobacco) in a volatile form have been employed against bird lice and fleas. The liquid is painted over the perches on which the birds roost ; during the night the warmth of the birds causes a vapour to arise which penetrates their feathers, destroying the parasites without injury to the fowls.

It must be confessed that one serious pest, the Sheep Maggot-Fly, has so far not been overcome by modern science. This insect, or rather insects, for there is more than one species, lays its eggs in the wool of sheep ; and the maggots which hatch out feed upon the flesh of the unfortunate sheep, causing much pain, and even death, for in hill districts " struck " animals may wander off and perish before they can be discovered and treated. It is, of course, possible to cure " struck " sheep by individual attention and local treatments with sulphur and other compounds. What is urgently wanted, however, is information about the quality in sheep's wool which attracts flies, because this may lead to the successful use of deterrents, and up to the present no such efficient substances have been discovered.

Turning now to a consideration of insect and allied pests attacking farm crops, modern science tends to emphasize more and more strongly the necessity for sensible crop rotations and good farming methods in the control of these parasites. Modern farming, particularly the more intensive forms, provides pests and fungus diseases with almost unlimited opportunities for development. Food is often the limiting factor in the multiplication of insects, and the crowding together of individual plants into a crop offers every inducement for a pest to begin and continue its destructive work.

If a crop like potatoes is grown year after year upon the same land, an uninterrupted supply of food becomes available for any enemy which is partial to this plant. In some fertile parts of the country potatoes are actually grown several years in succession upon the same land. Gradually the yield diminishes ; in farming phraseology the land became " potato-sick." The cause is partly the increase in numbers of an eelworm which lives on the roots of the potato. If potatoes are followed by barley or oats, then by a clover ley, then by wheat, *i.e.* if the four-course rotation is adhered to, potatoes occupy the land only once in four years. The parasitic eelworm then has a year of plenty, followed by three lean years, and consequently gets little chance of development. Once the pest has multiplied, it may be many years before it is safe to plant the crop again.

Rotations are particularly necessary in protecting crops from pests which spend all, or nearly all, of their existence in the soil. The potato eelworm and the stem eelworm behave in this way. The female potato eelworm spends the summer months attached to the roots of the potato below ground ; its eggs and the young larvae which hatch from them also live below ground level. The only ways in which the worms can be distributed are accidental—in soil adhering to the lifted roots, to the boots of workers, and so on. The stem eelworm, which attacks clover, oats, bulbs, and so on, has a some-what similar life history, though it may be rather more readily distributed by adhering to parts of the affected plants.

Neither of these soil pests has the same facility for self-dispersal as the wireworm, leather-jacket, or cutworm. The first two of these insect enemies are larval forms of the Click Beetle, and Daddy-long-legs (Crane Fly) respectively, whilst cutworms are caterpillars of various moths, such as the Turnip, Heart-and-Dart, and Yellow Underwing. Although the larvae are soil-living, the adult insects all have the power of flight, and can consequently become dispersed with considerable ease. Wireworms and leather-jackets find long duration grassland very much to their liking, and although they may do damage to the roots of grasses, this is insignificant compared with the destruction they bring about when the grassland is ploughed and sown with a straw or root crop.

Wireworms, as already stated, have so far defied the efforts of science and practice to destroy them at an economic price. Soil fumigation with naphthalene and other products has been successful in some cases, but it is an expensive and uncertain operation. Leather-jackets and cutworms, however, which feed on the surface of the soil, may be killed by an attractive poison bait made of a mixture of Paris Green (a substance containing arsenic) and bran. About 1 lb. of Paris Green and 30 lb. of moistened bran well mixed together are broadcast over an acre of land ; if the weather be warm and not too dry large numbers of the larvae are destroyed through eating the poisoned bait.

Slugs, which are sometimes a very serious pest in fields and gardens, can also be attacked with this poison bait, but quite recently a substance much more deadly to slugs has been used. This is metaldehyde, a substance which enters into the composition of the solid fuel sold for use with camp stoves. It was discovered that metaldehyde, mixed with bran, is extremely attractive and very deadly to slugs, whilst it is probably less dangerous to use than Paris Green. It is, however, ineffective against leather-jackets. The bait is composed of 1 stick (about 4 grammes) of the proprietary fuel to 2 pints (about ½ lb.) of bran.

Whilst the intelligent use of rotations may do a great deal to prevent or minimize attack by pests, the study of the life histories of the pests themselves sometimes indicates that cultural methods may be adapted towards insect control. The Frit Fly which attacks spring oats is an example. The female lays her eggs on the young oat plant during May, and the larvae feed upon the central shoot. This is destroyed, and though lateral shoots, or tillers, may develop, the crop is much reduced. Subsequent broods of flies may attack the developing grain. The younger the oat plant at the time the flies emerge the more it is attacked. Early sowing is one of the greatest safeguards against this pest, and February sown oats are much less likely to suffer serious damage than oats sown in April.

The frit fly problem illustrates, too, another method which is being used to combat insect and allied pests. This is the breeding of resistant varieties. Obviously, if a variety of oat could be obtained entirely resistant to attacks by the frit fly, the problem, so far as this pest is concerned, would be solved, Unfortunately, however, it does not follow that resistant varieties are good croppers, so that the problem is to obtain resistance combined with good quality and yield. Research on these lines is proceeding at Oxford and elsewhere, but it is too early to speak of its commercial results.

COLLATERAL READING

An elementary account of the structure and habits of insects, together with descriptions and illustrations of the chief farm pests, is to be found in *Agricultural Entomology*, by Robinson and Jary (Duckworth, 1929). Farm pests are also dealt with in Kenneth Smith's *Agricultural Entomology* (Cambridge University Press, 1931). The Ministry of Agriculture and Fisheries issue leaflets and booklets dealing with the principal farm pests and methods of controlling them, and these are revised at intervals. Information about virus diseases and the part played by insects in their dissemination can be obtained from *Recent Advances in the Study of Plant Viruses* (J. and A. Churchill, 1933), and *Plant Virus Diseases* (Churchill, 1937), both by Kenneth Smith. Bailliere's *Encyclopædia of Scientific Agriculture*, Volume I., contains several articles dealing with farm insects, both harmful and beneficial. *Insect Pests and Fungus Diseases*, by Fryer (Cambridge University Press, 1920), may also be consulted.

CHAPTER VII

PLANT DISEASES

THE most important diseases of farm crops in this country are caused by fungi. Bacteria, and those little understood agencies called viruses, also attack farm plants, but they are by no means so destructive as the fungi.

Plant diseases are very expensive, both to the individual farmer and also nationally. They have even had, in the past, important political consequences. The failure of the potato crop in Ireland, about the middle of last century, brought about by the " blight " fungus (*Phytophthora infestans*), led to widespread famine and misery, depopulated Ireland, and caused the immigration into Liverpool, Glasgow, and the United States of America of hundreds of thousands of Irish. Such a calamity as this famine cannot fail to impress upon the minds of everybody the potentiality for evil which certain fungi possess ; but in less spectacular ways fungus enemies take a tremendous toll upon food production, leading to losses which are none the less real though often unsuspected. It is said, for example, that the common Yellow Rust of the wheat plant every year diminishes the yield of the crop from 5 to 10 per cent. That is to say, the nation loses about 120,000 tons of wheat every year from this disease alone. In these days, when the production of more and more food at home is regarded as a national necessity, such a wastage cannot be ignored, and it becomes a matter of general interest to learn something about plant diseases and the methods which are being used to fight them.

Fungi are remarkable things, both in their variety and mode of life. They range from the tiny yeasts which cause fermentation to the large toadstools so common in fields and woods. They all agree in having no green colouring matter or chlorophyll; and this characteristic prevents them from making their own food in the way that green plants synthesize it from the carbon dioxide of the air and the mineral matter of the soil. Fungi must get their food from living or dead animals or plants; if the first, they are called parasites; if the second, they are called saprophytes. It is the parasitic fungi which cause plant disease, but it should be remembered that many non-parasitic fungi are very useful in agriculture, since they cause decay, or rotting, of farmyard manure and other organic matter, without which farming would eventually become quite impossible.

Now, in the fight against plant disease science has to proceed in an orderly fashion. First of all the cause of the trouble has to be identified, and this is not always easy, because the parasitic fungus may be accompanied by non-parasitic species, and their separation offers difficulties. Then the mycologist (the man or woman who studies fungi) has to trace out the life history of the parasite, find out how it is spread, and then think out how best to attack it.

Let us take the case of the Wart disease or Black Scab of potatoes. Round about 1902 it became known that potato growers in parts of Shropshire and Lancashire were becoming seriously alarmed on account of a disease

Healthy and Leaf Roll affected potato plants
with their produce.

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Ministry of Agriculture, by permission of the
Controller of H.M. Stationery Office.

which attacked the tuber. Instead of nice clean potatoes they were digging up badly warted tubers having large, cauliflower-like excrescences of a brownish or blackish colour. At first these " warts " were firm and hard, but soon the whole potato rotted down into a shapeless mass. The losses in certain parishes were very considerable. Investigations showed that a lowly form of fungus, named *Synchitrium endobioticum*, was responsible. It lives in the outer layers of the potato tuber, which are distorted into the " warts," and it not only forms thick-walled resting spores in the tuber, but it also releases other spores into the soil. Both kinds of spore can spread disease. It was found, also, that these spores are very long lived, so that even if potatoes were not on the land oftener than once in eight years, the possibility of the complaint cropping up again with the next planting could not be ruled out.

This was a very serious state of affairs, especially as the disease was rapidly spreading with the distribution of infected seed potatoes. It appeared at one time that the cultivation of potatoes in infected soils would become impossible, since no practical method of sterilizing farm soils was forthcoming. It was noticed later, however, that different varieties of potatoes reacted differently to the disease when grown on infected soil. Most varieties developed the warts on the tubers, but a few yielded perfectly clean potatoes. This simple observation—and it should be remembered that science is merely systematic observation—led to the control of the disease, for it was later made quite clear that some potato varieties, such as Kerr's Pink, Great Scot, and Majestic, are entirely immune. These varieties can be grown on wart disease infected soil without contracting the complaint, but obviously it would be very unwise to use such potatoes as seed on non-infected land, because of the danger of spreading the spores.

Consequently, for the protection of potato growers generally, the Ministry of Agriculture, under the Wart Disease of Potato Order, 1923, have made it compulsory for growers to notify the police if the disease appears in a hitherto uninfected area. The growing of non-immune varieties in infected soil is forbidden, and seed potatoes from an infected area may not be planted in non-infected areas.

The testing of new varieties of potatoes—and dozens of these are sent for trial every year—for susceptibility to wart disease, is now a very important branch of work carried out by the National Institute of Agricultural Botany. The trial grounds are at Ormskirk, in Lancashire.

Wart disease is not the only serious complaint that the potato grower has to contend with, and for which he seeks the aid of the scientist. The Blight, or " Potato Disease " fungus has already been mentioned, and it still is one of the most serious farm diseases. Modern science has so far been able to suggest no better means of controlling the fungus than spraying with Bordeaux or Burgundy mixtures, and these were invented many years ago. The Bordeaux mixture dates from about 1882, and is a combination of copper sulphate and lime. The usual method of preparation is to dissolve 12 lb. of copper sulphate in water, add 6 lb. of freshly slaked quicklime, and make up with more water to 120 gallons. This is sufficient to spray one acre of potatoes. Sometimes the mixture is made double this strength. Burgundy mixture dates from 1887, and 15 lb. of washing soda are substituted for the lime. The chemistry of these two mixtures has received a great deal of attention but is still not properly understood. It appears that a very fine precipitate of a copper compound is formed when the mixture is prepared, and when this is sprayed as a fine mist upon potato plants, a thin layer covers the surface of the leaves. This layer is toxic to the developing spores of the disease fungus, and so protects the plant from invasion. Spraying potatoes with either of these preparations is, of course, entirely a preventive measure. Modern science has not yet discovered any means of curing a plant once the fungus has made its entry, nor has it yet been able to breed a satisfactorily yielding potato which is immune to blight.

Scientific interest in potatoes has rather shifted to the problem of virus diseases, which are very harmful to the potato and also to other plants of less farming inportance. It has been realized for a long time by farmers that if they save their own " seed " potatoes and plant them year after year on their own farms, the yield gets smaller and smaller. The seed " degenerates," and fresh seed from a different locality must be obtained if profitable crops are to be grown. Until recently this degeneration of potato stocks could not be explained, but investigations, particularly since the war, show that it is due, to a large extent at any rate, to virus diseases.

A virus disease may be defined as " an infectious disease caused by something which cannot be seen under the highest powers of the ordinary microscope." These complaints occur in animals as well as in plants, for foot-and-mouth disease in cattle, smallpox and scarlet fever in human beings are due to viruses. It is uncertain whether a virus is a soluble substance similar to an enzyme, or a separate living organism like a bacterium. Whichever it may be, a virus is capable of passing through the excessively tiny pores of an unglazed porcelain filter which would retain with ease the smallest known bacterium ; hence the term " filterable virus," so commonly used. Another characteristic of most viruses is their inability to multiply outside the cells of the plants or animals which they normally inhabit.

The financial losses caused by viruses in animals need no stressing, because every one is aware that the recent outbreaks of foot-and-mouth disease have cost the country several hundreds of thousands of pounds. Virus diseases in plants may not be so spectacular, but the losses due to them are very considerable. The loss in yield of the potato crop in North Wales due to leaf roll alone, was for several years estimated at about 50 per cent. In Lancashire and Cheshire the losses from the same virus have been put as high as 61 per cent.—the financial loss in some instances amounting to £5, 15s. per acre.

So far as the potato crop is concerned, the worst virus diseases are " Leaf Roll " and " Mosaic." In leaf roll the leaves begin to roll upwards from the edges, starting at the base of the leaf. They also become thickened, harsh, and leathery to the touch, and starch accumulates. The degree of rolling varies in different potatoes, and it may or may not be accompanied by changes in colour. " Mosaic " diseases are not so easily described, because there are so many different forms. It seems quite clear that several different viruses cause different kinds of mosaic diseases, but unfortunately the same virus is capable of giving rise to different symptoms in different potato varieties. This makes the study of the viruses very difficult, and has led to much confusion in the past. Kenneth Smith states that the Potato Virus Y is one of the commonest and most destructive viruses in the country. It gives rise to a blotchy mottle which spreads from the veins of the leaf, the veins turn brown, and eventually the whole leaf collapses. In other mosaic diseases the mottling may be accompanied by yellowing and crinkling. It has been stated that 90 per cent. of the potato stocks of England are infected by mosaic of one form or another.

All virus diseases of the potato can be spread if a healthy plant be grafted into an infected plant, and *vice versa*. Many virus diseases can be inoculated into a healthy plant if a drop of sap from an infected plant be scratched into the tissues of a healthy plant with a needle. Leaf roll, however, cannot be artificially spread in this manner. In nature, inoculation is performed by certain small insects, the most important of which is one of the aphides (greenfly or plant lice) called *Myzus persicae*.

When an aphis of this species sticks its slender, tubular, sucking apparatus into a virus-infected potato plant and sucks up the sap, the virus comes along as well. If the aphis then begins to feed upon another, virus-free plant, its saliva introduces the virus into the fresh puncture, and the damage has been done—inoculation has taken place. This procedure can take place not only on plants growing in the field as a crop, but also during the winter months in seed tubers set up for sprouting.

Potato growers in England have for many years obtained their seed from Scotland or Northern Ireland, because experience has shown that these stocks are less likely to show signs of degeneration than the English stocks. The relative freedom of Scots and Irish seed potatoes from virus diseases is attributed to a relative scarcity of virus-carrying aphides. The Scots and Irish seed potato industy is a very important one. It is important to the seed growers themselves, and it is valuable to farmers in England who require good seed if they are to make a profit from their own crops of cooking potatoes. A bigger supply of better seed would obviously benefit the whole industry.

The investigations upon virus diseases just described, and the discovery of the insect responsible for most of the spread of the disease, has enabled farmers in North Wales to break into the circle of seed potato suppliers, and their seed is now recognized as at least equal to any other. A great deal of science and a lot of organization went to the formation of this new agricultural industry.

First of all the investigators (the Agricultural Department of University College, Bangor) had to find out in what areas the spread of virus diseases was slowest. These areas were found to possess only scarce populations of aphides compared with other areas in which degeneration was rapid. Experiments extended over nine years showed that stocks grown in these areas cropped as well as imported Scotch seed. The next thing was to try out the scheme commercially. Farms in approved areas were selected, and all the farmers' potatoes, no matter how vigorous they might appear, were completely removed lest they might be virus infected. The farms were restocked with seed authorized by the College, and the crops were inspected at least three times during the growing season, any suspected plants being at once removed. Seed from the stocks was placed in special bags. The seed was found to be of such high quality over a number of years that in 1935 the Ministry of

Agriculture put Welsh seed on a level with Scots and Irish seed. During 1936 over seventy growers in North Wales were producing some 250 tons of virus-free seed potatoes under the supervision of the College. Good stocks of potatoes are now being produced in Cumberland and Westmorland as well.

The success of the scheme points to a solution of the virus disease problem in potatoes. Of course, the North Wales scheme was assisted by the fact that potatoes in that district are usually grown in small isolated patches, but the first requisite is an area which has a low infestation of the virus-carrying aphis. The discovery of the relationship between the number of certain aphides and the size of potato crops is one of the romances of modern scientific agriculture.

A " seed " potato is, of course, not a true seed but a swollen underground stem ; nevertheless it is always spoken of as seed, and for our immediate purpose may be considered as such. The control of potato degeneration has been shown to be a matter of controlling the " seed ": by sowing clean and non-infected seed a good crop for one or two years may be reasonably expected.

Quite a number of other important crop diseases are spread by seed, and during recent years very great advances have been made in methods of controlling these. The most important seed-borne diseases of farm crops are Bunt, or Stinking Smut, of wheat ; Smut, of barley and oats ; Leaf Stripe, of barley and oats ; and Blackleg, of sugar beet and mangolds.

In order to show how the control of these diseases is being achieved, the case of Bunt of wheat may be considered in some detail. Just before harvest the ears of wheat may be found to contain not normal, healthy grains, but grains filled with a dark powdery substance, smelling of rotting fish. These grains are obviously useless for food, and they may also render objectionable those healthy grains with which the bunt dust, or spores, comes in contact. The disease has been known for thousands of years; bunted wheat was spoken of as being "blasted" or suffering from a distemper, and in the days when famine was a frequent visitor to civilization, the incidence of bunt was very understandably attributed to Divine wrath. It was not until about 1800 that the black dust of bunt was shown to be composed of countless numbers of individual fungus spores.

From the middle of last century the life history of the fungus has been well known. The spore dust liberated by the bursting of infected grains sticks to the outside of healthy grains, particularly along the furrow and amongst the hairs at the top. When this contaminated seed germinates so do the spores, and the fungus grows along with the wheat plant until it finally enters the developing grain and forms its dark brown spores. Until this happens it is not possible to tell that the plant is infected by the parasite.

Even before the cause of the disease became known, crude attempts were made to disinfect seed wheat before sowing, in the hope of reducing the serious losses caused by bunt. Students of old agricultural journals, magazines, and books published 150 or more years ago will find much interest and some amusement from descriptions of old-time methods of "pickling" seed wheat. Extraordinary mixtures were recommended usually consisting of the most evil-smelling substances available.

Soot, salt, chamber-lye, extracts from manure heaps, and so forth—most of them of very little fungicidal value—were used, but with very little benefit. The only substance to give any control was copper sulphate, or bluestone, and during the middle of last century this became the standard dressing against bunt.

Unfortunately, in the strengths usually used to kill the bunt spores, the copper suphate has a bad effect upon the germination of wheat, especially if the grains are at all damaged or cracked. But until as recently as 1920 copper sulphate solutions in concentrations of from 1–10 per cent. were almost exclusively used in this country for the control of bunt. In 1921 a new method of disinfecting wheat grains with weak solutions of formalin was devised. It was shown that, if properly carried out, the formalin method not only kills the fungus spores more efficiently than copper sulphate, but has no ill effects at all upon germination. In a few years the formalin method had almost ousted the copper sulphate treatment.

But treatment with formalin solutions, though effective, suffer from disadvantages common to all watery disinfectants. Fluids cause the grain to swell, and this may affect its delivery along the spouts of the drill ; wet grain must be dried before it can be sown, or it sticks together in a mass ; and most important of all, the grain must be sown within about twenty-four hours of treatment, or it loses its vitality to a tremendous degree. The farmer cannot control the weather, and conditions immediately after " pickling " has been performed may make it impossible to drill the seed. For these reasons a dry disinfectant powder was much to be desired.

About 1917 finely powdered basic copper carbonate was used by Darnell Smith in Australia to control bunt. He found that about two ounces well mixed up with a bushel of grain destroyed the spores without damaging germination. Treated grain could be stored indefinitely without losing its vitality. This discovery was not properly appreciated at its full worth for another ten or twelve years, partly on account of the war and partly because of the success of the new formalin treatment just described. About 1928 the copper carbonate dust method of seed disinfection was taken up with enthusiasm by seed firms, some of which arranged to send out seed wheat already treated with the powder. From a practical point of view this was a great advance, and for the first time in the cultivation of the wheat crop the farmer felt safe in neglecting to pickle his seed. Copper carbonate is poisonous if breathed in in quantity, but a pad of cloth over the user's mouth is all that is needed to protect an operator. Thorough mixing of seed and copper carbonate is very necessary, but it was soon found that an old end-over-end butter churn makes a very useful mixer for use on the farm, and in a very short time many of these converted churns were being used by farmers who preferred to dress their own seed wheat. Copper carbonate dust has now been superseded by other dry disinfectants, as will be shown later.

Bunt, or Stinking Smut, has been dealt with at this length in order to show what rapid developments have taken place recently in the control of seed-borne diseases. Of course there are other seed-borne smuts—there is the Loose-smut of wheat and barley, for example, in which the whole ear may rot away into a black powder. Science is at the moment baffled by these two diseases, because the fungi which cause them are hidden deep within the seed itself. They cannot be destroyed by external pickling; it is possible to kill the fungus by immersing the seed for four hours in water at a temperature of 52–54° C. (125°–129° F.) without killing the grain, but practical difficulties make it almost impossible to use the method on the farm. The best precaution against these diseases is to sow seed which is known to have come from a clean crop. Then there are other seed-borne diseases such as the Smut of oats, Leaf Stripe of oats and barley, seedling Blight of rye, and Blackleg of sugar beet and mangolds.

Copper carbonate is not so effective against the smut of oats as it is against bunt, but it does give a control. Against the other diseases it has not been found of much use.

Those who know anything about germicides might wonder why mercuric chloride, popularly called corrosive sublimate, has not been mentioned as a seed disinfectant. Early experiments with this substance, carried out about 1890, gave poor results in controlling smuts of cereals, and it was not until 1915 that the possibilities of the compound were realized. It was then discovered in Germany that mercuric chloride would control the fungus responsible for seedling blight of rye. This was a valuable point, because the fungus which causes seedling blight lies actually within the seed. There are no spores on the outside of the grain as in the case of bunt, and it seems probable that the mercuric chloride lies in wait, as it were, for the fungus to start growing during the germination of the seed before it attacks and destroys it.

Mercuric chloride is so very poisonous that other mercury compounds, described as organo-mercury derivatives, were experimented with. The preliminary work on these was almost entirely carried out in Germany by commercial firms, and the substances themselves became known only under their trade names. " Uspulun " consisted of " chlorphenol-mercury " plus sodium hydroxide, and was used as a wet steep or pickle. The success of the dry copper carbonate dust, however, led to developments of dry organo-mercury powders ; two of the best known of these are " Cerean," a German product, and " Agrosan," which is made in England.

These mercury compounds appear to be even more efficient than copper carbonate in disinfecting seed. Not only do they prevent bunt in wheat, the smuts of oat, and covered smut in barley, but they also control leaf stripe in barley and oats. Leaf spot and leaf stripe, or Helminthosporium disease of oats, has in recent years become an extremely destructive disease, notably in certain parts of Scotland, causing very considerable losses. The crop may die off badly in the seedling stages, or later may develop long brown stripes on the leaves followed by a partial or complete failure of the ears to develop. Until the development of these organo-mercury dusts the disease could not be controlled, but now it is possible to disinfect the seed before sowing and so get satisfactory crops. The cost of treating cereals usually amounts to less than 1s. per acre, and treated seed can be stored for a long time without being damaged. Like copper carbonate, these dusts are poisonous and must not be inhaled.

During the last thirty years a great deal of attention has been paid to the control of fungus diseases by means of spray fluids. On the average farm very few of these sprays are ever used, but for the protection of fruit and horticultural crops this branch of modern science is of ever-increasing importance. Information concerning the fungicidal sprays, which hardly come within the scope of this work, can be obtained from books mentioned at the end of this chapter.

COLLATERAL READING

A general account of the Fungi is to be found in *The Structure and Development of the Fungi*, by Gwynne-Vaughan and Barnes (Cambridge University Press, 1927), whilst most of the plant diseases of this country receive treatment in F. T. Brooks's *Plant Diseases* (Oxford University Press, 1928). Heald's *Manual of Plant Diseases* (McGraw-Hill Book Company Inc., 1926) is an American work, which gives interesting historical accounts of fungus diseases as well as a full treatment of each disease. These three books are heavy reading for the non-scientific ; a lighter and more immediately practical account of plant diseases is to be found in the leaflets and booklets issued by the Ministry of Agriculture and Fisheries through the Stationery Office. A useful elementary book on the subject is *Fungoid and Insect Pests of the Farm*, by Petherbridge (Cambridge University Press). The latest information on spray fluids used against fungi can be obtained from Martin's *The Scientific Principles of Plant Protection* (Edward Arnold and Co., 1936), though the treatment is again mostly technical. Virus diseases are dealt with in the books referred to in the previous chapter. The principles of disease and pest control are explained by Fryer in non-technical language in *Successful Spraying and how to achieve it* (Ernest Benn, Ltd., 1923).

CHAPTER VIII

SCIENCE AND ANIMAL DISEASE

Scientific investigation and experimentation have done a great deal during recent years to help the farmer in his fight against the diseases of farm animals. Farming is a much more complicated thing now than it was fifty years ago, and the veterinary surgeon, no less than the medical doctor, finds that this complexity tends to assist the development and spread of complaints which formerly were unknown or considered of little importance ; it also accentuates the difficulty of dealing with old established diseases such as tuberculosis and foot-and-mouth disease.

The crowding together of large numbers of farm animals, made necessary by certain systems of farming ; the unnatural forcing of the females to ever-increasing efforts of production ; systems of feeding which reduce the freshness of the food supplied ; all these factors increase the possibilities of epidemic disease, whilst modern methods of rapid transport make it possible for diseases to be transferred very quickly from place to place.

It is the veterinary surgeon's job not only to deal with what one may term the ordinary ailments of farm livestock, but also to investigate means of controlling and preventing other nationally important animal diseases like tuberculosis, foot-and-mouth disease, Johne's disease, contagious abortion, liver rot, bacillary white diarrhoea in poultry, distemper in dogs, and so on. The advances made in veterinary science have been so great during the present century that it is possible to refer to a few only of the most important developments.

One disease of animals which is always in the minds of the public as well as of the farmer is Tuberculosis, familiarly referred to as "T.B." Tuberculosis, or scrofula, has always been known, from the very earliest times, as the most prevalent disease suffered by human beings. The importance of tuberculosis in farm and other animals, however, has only been recognized comparatively recently. The characteristic symptoms of the disease are the small nodules, or swellings, which later become cheesy in texture. In the public mind tuberculosis is always associated with the lungs, in which case the disease is called " consumption," or phthisis. But the germ of tuberculosis can attack almost any part of the body—intestines, bones, glands, or skin. The disease need not necessarily cause death, but it seriously impairs the health and activity of its victims.

Modern research into tuberculosis dates from 1882, when Robert Koch proved that, both in animals and in man, the disease is caused by a specific bacterium. It is now customary to speak of three different types of tubercle bacilli, namely, human, bovine, and avian. The first type is the chief cause of tuberculosis in man, particularly of pulmonary consumption. The bovine type causes practically all the tuberculosis in cattle, whilst the avian type is almost the sole cause of the disease in poultry. Actually, bacilli of the bovine type can and do infect human beings, particularly the alimentary tract and the bones, whilst pigs are susceptible to tuberculosis of the avian type, as are cattle to a less degree.

These discoveries are obviously of great significance. They show that the importance of tuberculosis in farm livestock is not confined to the animals themselves, but that it is a matter of national concern. From a more immediately practical standpoint the new information shows how undesirable it is to allow poultry to use pastures frequented by dairy cattle or by pigs. Very recent investigations have shown, on the other hand, that the germs of tuberculosis do not survive more than a few weeks when exposed to sun and air on the grass of pastures, so that there is not so much risk of infection being picked up from this source as was formerly supposed.

An animal may be tuberculous and yet manifest no external symptoms for a long time. It is obviously very desirable to be able to detect such an animal by means of a routine test, since the unsuspected case may be infecting its neighbours over a considerable period. The tuberculin test has greatly assisted in the fight against tuberculosis. Tuberculin is prepared by growing tubercle bacilli on various culture materials in glass vessels, extracting the cultures in water, sterilizing, and filtering. The result is a clear or brownish-yellow oily fluid, which is used in various ways. In the subcutaneous tuberculin test the liquid is injected under the skin ; if the animal is tuberculous its temperature gradually rises, until between the twelfth and twenty-first hour after inoculation it is from 2° to 5° F. higher than it was before the operation. Healthy animals do not react in this way. In the intradermal test, tuberculin is injected into a fold of the skin. In positive reactions a painful swelling develops and

A preliminary stage in the examination of milk for tubercle bacilli.

Filling a hypodermic syringe with sediment from a centrifuged sample of milk preparatory to inoculating it into a guinea pig.

(*Photo, D. H. Robinson.*)

the fold of skin increases in thickness. In the opthalmic tuberculin test a few drops of tuberculin are dropped into the corner of the eye. A positive reaction manifests itself in a watering of the eye, reddening, and slight swelling ; an elongated mass composed of a dried-up discharge from the eye may also form.

The investigations conducted during the last half-century have shown that heredity plays only a very small part in spreading tuberculosis. The disease is infectious, transmissible from animal to animal and from animal to man, and can be detected by the proper use of the tuberculin test. The eradication of tuberculosis in farm stock, most important in the case of dairy herds, is consequently a more practical proposition from a scientific point of view than ever before. The limiting factor is the capital cost involved in the destruction of reacting animals. It has been shown in this country, as well as in Sweden, Denmark, and Norway, that a great reduction in tuberculosis can be brought about by destroying infected animals, by separating and isolating reactors to the tuberculin test, which are otherwise apparently healthy, and by feeding calves of these reactors with tubercule-free milk. The carrying out of such a scheme of eradication, though scientifically sound, is in practice complicated and full of all sorts of difficulties which so far have prevented concerted action throughout the whole of the country.

Numerous attempts have been, and are being, made to immunize animals against tuberculosis by means of vaccines. The best method of protective vaccination so far devised appears to be the " B.C.G." method, devised by two French workers, Calmette and Guérin. These two scientists obtained a strain of tubercle bacillus from a cow in 1907, and for thirteen successive years cultivated it upon slabs of potato soaked in ox bile and glycerine. At the end of this period it was discovered that the germs, though unchanged in appearance, had become so attenuated, or weakened, that they were unable to infect with tuberculosis a calf into which they were inoculated. Furthermore, it was found that calves treated in this way did not contract the disease when artificially inoculated with germs of ordinary bovine tuberculosis in amounts sufficient to cause severe tuberculosis in untreated animals. Since then numerous trials have shown that, when used in the proper way, Bacillus Calmette Guérin can create a high degree of resistance to tuberculosis. Immunization by vaccines is still in an experimental stage, but since tuberculosis in farm animals is not a disease that can be cured, the whole trend of scientific thought is in the direction of prevention.

Another very serious disease, especially in dairy herds, is contagious, or epizootic, abortion. In this disease the cow " slips her calf," that is, she aborts, or produces the calf prematurely, usually in a non-living condition. The cow itself usually recovers, unless complications ensue due to the retention of the afterbirth. As its name implies, this disease is liable to spread from one animal to another, so that in a dairy herd a considerable number of cows may in rapid succession slip their calves. This puts the cow-keeper in a very difficult position, because cows will not milk satisfactorily unless they calve down naturally ; the expected yield of milk is not forthcoming at the right time, and the cow-keeper either has to buy cows in milk or extra milk itself to fulfil his contract. The loss of the calf is usually of secondary consideration, except perhaps in pedigree herds ; recently it has been shown that cows infected with germs of contagious abortion give considerably less milk than healthy animals.

It was not until 1896 that contagious abortion was proved to be caused by a specific bacterium, though it had been suspected many years previously that such is the case. This new knowledge did not prove very helpful at first, because too little was known about the way in which animals are infected, and because there was no means of finding out if a cow was infected until she actually aborted. All sorts of sanitary measures were recommended, based upon general bacteriological knowledge, such as the washing out of the genital passages of the cow with antiseptics, the disinfection of the cowshed, and so on. Later it was found possible to detect the presence of the germ in an animal by means of the agglutination test (p. 144), and the discovery was made that the disease exists in the majority of herds throughout the country. The bacilli of the disease, however, though they may be present in the joints and lymph glands, only multiply readily if situated in the uterus or in the udder. They are usually spread, not as was at one time thought, by direct introduction into the genital duct, but along with food, water, and infected milk. They may be spread when an uninfected animal licks an infected animal.

These recent discoveries have made it possible to take fresh steps towards the eradication of contagious abortion. The infected animals can be detected by the agglutination and other tests, and they should be isolated from the healthy cows, or better still, kept on a separate farm. The calves of these infected animals may or may not contract the disease; even if they do become infected they may recover before they are a year old, and if they pass the agglutination test they can be taken back to the healthy farm. Segregation is the key to the problem of contagious abortion. On the Continent it is claimed that vaccination against abortion can be successfully accomplished, but the tendency here is to advise isolation in preference to the use of vaccines.

The control of contagious abortion is more than a matter for the cow-keepers of the country, because recent research has shown that the causal germ, *Brucella abortus*, not infrequently occurs in cow's milk as sold to the public. Now *Br. abortus* has been found to resemble very closely the bacillus responsible for Malta fever, or undulant fever, a painful human complaint prevalent in Mediterranean countries, but not unknown here. So far as is known at the moment, it is only particularly susceptible individuals who are likely in this country to develop undulant fever from germs present in cow's milk ; but the importance of ridding herds of both tuberculosis and contagious abortion needs no further emphasis.

The very important complaint in cloven-hoofed animals called Foot-and-mouth disease has lately attracted a great deal of attention from the general public. Foot-and-mouth disease is caused by a virus (p. 115), which leads to the development of small blisters in the mouth and between the toes of infected animals. It is seldom fatal, but it causes such a falling-off in milk yield and such loss of condition generally that its tolerance in this country cannot be considered except as counsel of despair ; hence the policy of slaughtering all infected animals and possible contacts, with compensation payable from the public purse. The discovery of the virus-like nature of the cause of the disease dates from 1898, and was due to Loeffler and Frosch; in 1922, Vallée and Carré showed that at least two different viruses may be concerned in an outbreak of foot-and-mouth disease, called respectively Virus A and Virus O. An attack by one virus does not protect an animal against an attack by the other virus. This fact makes the immunizing of animals by means of vaccines a very much more difficult matter than was formerly supposed. The study of the disease is made very difficult because the virus cannot be cultivated in glass tubes in the manner adopted for bacteria ; and although it has recently been shown that guinea pigs can be infected by injecting the virus into the skin, the extraordinarily contagious nature of the disease makes it impossible to study the behaviour of the virus except at a very few well-protected stations. For the time being, therefore, it must be admitted that science has done little to solve the problem of foot-and-mouth disease, beyond suggesting methods of slaughter and disinfection designed to minimize its spread. But for the fact that we are an island, these measures would be of little use if continental experiences are a guide.

Some of the most strikingly successful results of recent scientific investigation are to be found in the treatment of certain diseases of sheep. For example, round about 1920 a very serious complaint in young lambs was reported from Scotland and northern England, and later the disease moved south. It attacked young lambs a few hours after birth, causing a rapid scour, and ending in the death of the animals a few hours later. In some flocks the mortality amongst lambs reached 30 per cent. The disease was named "Lamb Dysentery," and post-mortem examination of infected lambs revealed characteristic yellow spots, about the size of a pin's head, along the small intestine. By 1923 Gaiger and Dalling proved that certain spore-forming bacteria of the anaerobic type are responsible for the disease. (Anaerobic bacteria are so called because they cannot exist in the presence of free oxygen, as in the air, for example; they must have an oxygen-free medium in which to live, though their spores behave differently.) They showed, too, that infection is picked up from the soil through contact, or by sucking the ewe's teats when contaminated with soil, or by contact with dead, infected lambs.

These discoveries led to the preparation of an antitoxic serum prepared from the causal organism. This serum can be inoculated into the ewe before the birth of her lamb; the lamb, on sucking milk, soon develops a substance in its blood capable of neutralizing the toxin formed by the parasitic bacteria. Lambs themselves may be inoculated direct. The immunity conferred by inoculation lasts sufficiently long to carry the lamb over the dangerous first fortnight or three weeks of its existence. The use of this serum has been startlingly successful, for when properly used it appears to be almost infallible. Tens of thousands of lambs are inoculated every year. Lamb dysentery provides an excellent example of the immediate benefits which veterinary science may confer upon the farming industry.

Another very destructive disease of sheep which is yielding to scientific treatment is liver rot. During the wet years from 1879–81 over three and a half million sheep died in England from this disease, and during the winter of 1920–21 some 60,000 sheep died in the four northern counties of Wales alone. The cause of the disease is a small flat-worm called a "fluke," which lives in large numbers in the ducts, or tubes, of the sheep's liver. The fluke itself is about an inch long, not dissimilar in shape to a flat-fish, or "flounder," for which it was at one time mistaken. For a long time it was thought that the fluke had nothing to do with "rot" in sheep, and all sorts of curious hypotheses were put forward to explain the cause. It was not until 1862 that flukes were definitely proved to be the cause of the disease, and it was another twenty years before the extraordinary life cycle of the parasite first became known. It is worth considering the life history of the liver fluke in some detail, because it illustrates very well how apparently unrelated scientific observations may gradually build up into a discovery of first-rate practical importance.

The fluke in the sheep's liver produces thousands of tiny eggs which pass out with the dung and reach the ground. In suitable conditions the egg hatches into a microscopic larva, capable of swimming in water; the larva perishes if, within about twenty-four hours, it does not find a certain species of fresh-water snail. Having found a suitable snail, the larva forces its way in and develops into a bag-like structure, which buds off internally to form half a dozen other creatures. These in their turn bud off internally to form a dozen or more individuals of small size, resembling tadpoles. These escape from the snail and eventually fasten themselves to blades of grass, when they are called cysts. If eaten by a sheep the cyst develops into a fluke, which finds its way to the liver, where it lives and increases in size.

This life cycle is one of the most extraordinary known to science, and it took one hundred and thirty years to piece together from the scattered observations of scientific men in several different countries. Once the true facts about the life history of the fluke were known, it became possible to explain several things which hitherto had puzzled the farmer. The reason why liver rot is most prevalent in wet seasons is that the necessary water-snails are then most abundant, so that more larvae can survive. Liver rot is uncommon in salt marshes because the snail cannot live in salt water ; rot is less common on dry farms than on wet marshy farms because dry conditions are unfavourable to the snails.

Recently a method of disinfecting watercourses and damp grassland has been devised, and the snails can be destroyed, or at any rate reduced in numbers, by the use of a mixture of finely-ground copper sulphate, kainit, and sand. The destruction of the water-snails cuts short the life cycle at the larval stage.

This method of attack, though helpful, is not sufficiently certain to be relied upon absolutely. Some means of dislodging the flukes from the sheep's liver became urgently necessary as soon as the fluke was recognized as the cause of rot. Extracts from the roots of fern proved, until very recently, the most successful of the many substances tried, but they were not entirely satisfactory. About 1925 experiments with carbon tetrachloride were begun, and in a few years a most successful technique was developed. The drug is administered in capsules of gelatine, and if dosing is carried out at the right time and with suitable precautions—and the operation is an extremely simple one—losses from liver rot can be kept down to a very small figure. Dosing with carbon tetrachloride, combined with the disinfection of damp places likely to harbour the fresh-water snail, have put great confidence into flock masters, who, until the last decade, felt almost helpless against the ravages of liver rot.

The life histories of some other parasitic worms have quite recently been worked out, and again we are confronted with an amazingly complicated series of events. For example, a serious coughing disease of pigs has been known for a long time, and it was discovered that white thread-like worms about two inches in length, resident in the lungs, are responsible. Until about 1929 it was not known with certainty how the worm got into the lungs, with the result that methods of prevention could not be devised very satisfactorily. In 1929 the two Hobmaiers were able to disclose the life cycle of the lung worm as follows. Eggs are produced by the female worm in the lungs, and these hatch at once, the young larvae climbing up the windpipe, or being coughed up, into the mouth, whereupon they are swallowed. They pass out of the body of the pig in the dung and reach the ground. They seem to be incapable of further development unless swallowed by an earthworm. Once in the earthworm they pass through another stage and then remain dormant. A single earthworm may contain hundreds of these partially developed larvae. If the earthworm is swallowed by a pig, a common occurrence as the animal roots about in soil, the larvae are released in the pig's stomach and proceed to bore through the walls of the intestines. After a few days' pause for development into the sexually mature stage, the parasites wander through the tissues of the pig to the region of the heart, where they bore into the blood vessels. Carried along in the blood they eventually reach the lungs, where the irritation they set up leads to coughing, and possibly to pneumonia.

The earthworm seems to be absolutely essential to the completion of the life cycle of the parasitic lung worm ; it follows that elimination of infected earthworms is a means of controlling the disease. If young pigs are raised in pens with concrete floors, infection becomes impossible ; similarly, if the disease appears in a herd, removal from infected ground to clean pens free from earthworms will prevent the complaint from spreading. Obviously, too, pig manure should be used for land over which pigs are unlikely to roam.

Perhaps an even more fantastic life history is to be found in the case of certain lung worms of sheep, and parasitic worms of poultry. Here the intermediate stages in development can only take place in the soft tissues of slugs or snails. Hence the recommendation is sometimes made that poultry pens should occasionally be dressed with salt and kainit to destroy slugs.

Although distemper in dogs is of little direct importance in farming, a brief reference to this complaint may be made on account of the great public interest in dogs of all kinds. Distemper is an extremely infectious disease, especially of young dogs, which in the past has been the despair of dog lovers who have felt quite helpless in the face of an outbreak. The infected animals either recovered or succumbed—that was all that could be said about it. In 1905 Carré showed that distemper is caused by an ultra-microscopic virus, but another twenty years elapsed before the whole matter was properly thrashed out and a satisfactory means of combating the virus could be devised. Laidlaw and Dunkin were able to infect ferrets with dog distemper, and for various reasons this simplified their investigations. Ferrets are much more susceptible than dogs to fatal attacks of distemper, and by using ferrets these two workers were able about 1926 to devise an anti-virus vaccine against distemper in dogs. Actually, anti-distemper treatment involves first of all an inoculation with vaccine, followed a week later by a small dose of living virus to ensure immunity. As a result of these investigations, distemper has lost much of its terror, and can now be regarded as a treatable disease.

Recent investigations into the composition of the blood of animals, carried out by Green and Dryère in this country, have had most spectacular successes in the treatment of a non-parasitic disease called Lactation Tetany. This complaint chiefly affects cows during the spring months. It occurs very suddenly indeed, the symptoms are alarming, and death in convulsions follows an hour later. One can imagine the distress of a cow-keeper if his animals succumb to a mysterious illness before even the veterinary surgeon can arrive. Until recently very little could be done for animals attacked by this little-known disease. Green and Dryère then discovered that the blood of smitten animals is very deficient in the element magnesium compared with the blood of healthy animals. Magnesium deficiency was found experimentally to cause severe nervous disorders culminating in spasms and convulsions; conversely, it was discovered that injections of soluble magnesium salts into a vein or under the skin temporarily raises the magnesium content of the blood sufficiently high to overcome the nervous irritability, giving the animal a chance to recover. The present-day treatment for lactation tetany is therefore the injection of a small quantity of Epsom-salt (magnesium sulphate) into a vein or under the skin by means of a hypodermic syringe. What actually causes the reduction of magnesium in the blood is not fully understood.

During the last twenty years poultry keeping, both on specialized and on mixed farms, has undergone great developments, and there has been a correspondingly great increase in the attention devoted to poultry diseases. The rise of mass production methods in poultry rearing, and the use of battery brooders whereby the birds are housed tier upon tier in miniature skyscrapers, have made it possible to keep enormous numbers of poultry on a very small area of ground. Concentration of livestock in this manner makes the diagnosis and treatment of diseases very important indeed, not only on account of the capital involved, but also because diseases can spread very rapidly in such circumstances.

One of the most destructive poultry diseases is that known as Bacillary White Diarrhoea, usually shortened to B.W.D. This is a disease which chiefly attacks young chicks shortly after hatching, and it has in the past caused tremendous losses. The chicks appear stupid and lethargic, and there is a whitish discharge from the vent. They may die off very rapidly. It has been known since 1908 that the cause of the disease is a bacterium called *Salmonella pullorum*, but not until comparatively recently was it proved that infection comes mainly from the egg itself. In other words, the bacillus is already in the egg at the time of laying. Not all the chicks which contract the disease die ; some survive, and the germs remain within their bodies as they develop into pullets and adult hens. When these carriers lay eggs, the bacteria enter the embryo chicks, which from that moment are doomed to contract B.W.D. Infection may also be spread by the excreta of affected birds.

The discovery that adult birds may carry the disease in this way, without showing any external symptoms of infection, is a most important one, particularly as no successful treatment of diseased chicks is known. Prevention is obviously the best method of controlling bacillary white diarrhoea, and it is fortunately possible to detect the carriers by means of an agglutination test. For this purpose about forty drops of blood are taken from a vein under the wing and put into small tubes for testing in a laboratory. A pullet which reacts to the test should not be used for breeding purposes. It is the custom nowadays to buy breeding stock, day-old chicks, and eggs for incubation only if they are guaranteed to have passed the B.W.D. agglutination test. Naturally, other preventive sanitary measures are desirable, such as the removal of excreta and diseased chicks, and the disinfection of chick incubators.

Another extremely costly disease of poultry is Coccidiosis, which is caused by a microscopic, single-celled creature called a coccidium. Research carried out during the last quarter of a century has revealed the enormous capacity for multiplication possessed by coccidia, which explains to some extent the widespread nature of the disease. Coccidia are picked up by birds and develop in the lining of the intestinal walls. A single coccidium may give rise to one and a half million descendants, and the inflammation set up in the intestines leads to the death of many of the infected birds. Many of the coccidia pass out with the excreta, and so are liable to be picked up by the other birds using the same pen. The recognition of the fact that infection is spread chiefly through the droppings has led to the practice of rearing chickens on wire-netting floors; the droppings fall through beyond the reach of the chicks as they take their exercise.

Work carried out during the last twelve years has destroyed many illusions about yet another poultry disease, namely fowl pox or roup. In this complaint the skin becomes covered with pox-like lesions ; they are found in the mouth, on the comb, and round the eyes. Usually adult birds only are affected, with loss of condition and egg-laying power. Hitherto the disease has been considered extremely infectious, but Doyle and Minett have shown that it is spread by contact and that a virus is responsible. These two workers made the interesting discovery that it is very difficult to infect pigeons with virus of fowl pox, whilst pigeon pox is easily transmissible to fowls. They argued from this that it might be possible to protect fowls by vaccinating them with mild doses of pigeon pox, in much the same way as cow pox is used to immunize human beings against small pox. Since 1930 such a vaccine has been available, and its use has enabled poultry keepers to control fowl pox.

COLLATERAL READING

Excellent summaries in non-technical language of recent work in veterinary science are published annually in the Journal of the Royal Agricultural Society. The Ministry of Agriculture publishes at intervals leaflets and bulletins dealing with important diseases of animals. Consult also the *Veterinary Record*, published weekly.

CHAPTER IX

THE WORK OF THE BACTERIOLOGIST

THE work of the bacteriologist influences agriculture in many different ways. It is essential to the proper understanding of certain problems in soil fertility, in diseases of plants and animals, in the handling of milk, and so on; and whilst it would have been possible to deal with bacteriological work by spreading it over several of the preceding chapters, it has been thought preferable to devote a section specially to this branch of scientific investigation.

The term " micro-biologist " would be more accurate than " bacteriologist," for it has a wider meaning. A bacteriologist pure and simple deals entirely with bacteria, which form a distinct group of very small, very simple, plants called the Schizomycetes. The micro-biologist, however, is concerned with all the numerous tiny forms of life which may be found in the soil, and in plant and animal tissues. He has to deal not only with the true bacteria, but also with closely related forms of plants such as algae and fungi, and with lowly forms of animal life such as the protozoa. These very primitive animals may have a profound influence upon the bacteria in a soil, and they may also cause diseases in farm animals and poultry.

Some mention has already been made (Chapter VII.)

of the bacterial diseases of plants ; some of the more important diseases of animals caused by bacteria and protozoa receive attention in Chapter VIII. The present discussion is chiefly confined to the effect of micro-organisms upon soil fertility and the handling of milk.

Some account must, however, be given of the agglutination test, to which reference has several times been made in Chapter VIII. The agglutination test is a most useful one in diagnosing the presence of disease germs in living animals exhibiting no external symptoms of disease. The test depends upon the fact that the blood serum, that is the watery portion of the blood, of infected animals develops substances called agglutinins, which cause the disease bacteria to clump together and sink to the bottom of the vessel containing them. The test is carried out by taking a sample of blood from the subject under examination : assume that contagious abortion is suspected. After the blood has clotted some of the serum on top is mixed with a suspension of *Br. abortus*, the bacterial cause of the disease, and the tubes are incubated at body temperature for eighteen to thirty-six hours. No change occurs if the animal is free from the germs of contagious abortion. If the animal is a carrier of the germs there is a progressive flocculation, or clumping together, of the suspected bacteria, which sink to the bottom, leaving a clear liquid above. The agglutination test is not infallible, but it has undoubtedly been extremely useful in the diagnosis of germ carriers.

The soil, of course, teems with micro-organisms. Every gramme of rich soil contains millions of bacteria and protozoa. Many of them are responsible for decay or putrefaction, whilst others play a most important part in supplying nitrogen to farm crops. Some may be

Milk testing in a bacteriological laboratory.

(*Photo, D. H. Robinson.*)

dangerous to animals, such as the bacilli causing anthrax and tetanus.

Soil bacteriology, to use the more familiar term, is of recent growth, for it must be remembered that the nature of bacteria was unknown until Pasteur, about the middle of last century, laid the foundations of the science. When more and more became known about these lowly organisms it was realized that they are of great importance in farming. In the first place, it became obvious that bacteria, with various fungi as well, bring about decay. Decay is essential to the continuance of life. During decay, the bodies of animals and plants are resolved into their constituent elements, which return either to the soil or to the air, to be used again by other living organisms. Without decay a farm would become cluttered up with dead plant and animal remains, and life would sooner or later become impossible.

The farmer is particularly interested in what happens to the nitrogen of decaying material. In a manure heap, for example, bacterial changes may lead to a loss or a profit on the crop to which the manure is applied. Most of the nitrogen fed to an animal is returned to the manure in the urine. If bacteria get to work upon the urine-soaked straw much of the nitrogen may vanish into the air as ammonia.

Bacteriologists found that the bacteria which set free the combined nitrogen in the manure require a lot of air. They proved that if a manure heap can be trodden down very tight so as to exclude air, the loss of nitrogen during storage can be cut down to a minimum. That is why one often sees farm carts being drawn right over a manure heap before being unloaded. The trampling drives out the air. This discovery alone must have saved farmers many thousands of pounds during the fifty odd years that the compaction of manure heaps has been practised. A smell of ammonia coming from a loosely made heap of manure is a sign of harmful bacterial activity, which causes much of the cash value of the manure to escape.

Farmyard manure is becoming increasingly difficult to obtain, yet the strawy organic matter is known to be of great importance in maintaining fertility. Humus is essential for good crop growth and the retention of soil moisture. Scientists asked themselves if it would not be possible to make an artificial farmyard manure quickly and efficiently. To this end a careful study was made of the organisms known to be intimately concerned in decay, and in 1921 Hutchinson and Richards discovered a means of synthesizing organic manure. They found that the putrefactive organisms work very rapidly if they are supplied with plenty of soluble nitrogenous material and kept moist, and are given some basic substance such as lime to neutralize the acids they manufacture. In these circumstances the organisms will break down green vegetable matter in a few weeks to a substance very similar in appearance and chemical composition to farmyard manure. The nitrogen is usually given in the form of sulphate of ammonia. The process has been patented under the name of the Adco process, the special success of which, it is claimed, is due to the constituents added to the nitrogen, these differing with the class of vegetable refuse it is desired to rot down. Modifications of the process are used on farms on the Continent where there is little or no livestock to trample the straw. Calcium cyanamide alone has recently been used for a similar purpose. It is also employed to assis the rapid rotting of a green crop ploughed directly into the soil. The crop—mustard, vetches, rye, etc.—is flattened out with a roller and four hundredweights of calcium cyanamide per acre are broadcast. A few days later the green stuff is ploughed under and a tremendous bacteria activity ensues, leading to the enrichment of the soil with both organic matter and nitrogen. It is said, also, that the rate of decay is such that the underground stems of the weed called couch-grass, or squitch, are destroyed during the process.

Investigations into the habits of soil organisms have shown, too, that the stirring of a soil during summer actually causes an increase of soil nitrogen. Certain bacteria living in the upper layers extract nitrogen from the air to build up their tissues, and when they die the nitrogen becomes available to any crop growing there. The amount of nitrogen thus added to the soil may be worth over five shillings an acre. The process only goes on in a non-acid soil, and this is another reason why liming is so essential on many farms. This extraction of nitrogen from the air is very unusual, because most green plants are not able to utilize the tremendous stores of nitrogen in the air around them.

It is just over fifty years ago that the discovery was made of the reason why leguminous plants like clover and beans and lucerne are so rich in nitrogen, and why they leave the soil richer in this element than they find it. Two Germans, Hellriegel and Willfarth, proved that nitrogen-assimilating bacteria live in the nodules, or warts, so characteristic of the roots of leguminous plants. The bacteria steal a certain amount of food from the roots, and combine this with the nitrogen they take from the air. The nodules consequently become very rich in nitrogen, and the plant makes use of this when forming its own seed. Some of the nitrogen escapes into the soil, and this, together with the other nitrogen set free during the decay of the nodules, adds considerably to the fertility of the soil.

This discovery has a topical interest just now, on account of the interest being taken in the Soya Bean crop. No leguminous crop will grow really successfully unless the root nodules develop and the partnership between plant and bacteria is set going. Each plant has its own special form of root nodule bacteria, which alone will infect its roots. In our English soils there is usually a sufficiency of these organisms to infect all our crop plants. The soya bean is a foreign plant, however, and the required bacteria are not to be found here. Consequently the bacteria must be added to the soil before the crop will grow properly This is done by "inoculating" the seed with a culture of the required organisms. A culture is merely a narrow glass tube containing a jelly, upon the surface of which are growing countless numbers of nodule bacteria. The seeds are moistened with skim milk or other substance to make the germs adhere to them, and the jelly is shaken up, scattered over and well mixed in with the seed. The seed is allowed to dry in darkness and then sown as soon as possible.

Lucerne seed is inoculated in the same way. An important discovery was made by Thornton a few years ago to the effect that all types of lucerne root nodule bacteria are not equally effective. He selected out the best strains, cultivated them, and proved their worth. These improved strains are now available to the farmer at a low price. It costs about 3s. to treat enough seed to sow one acre, and very little lucerne is now sown without this preliminary inoculation. Inoculation can also be effected by scattering over the seed some air-dry soil from a field in which lucerne is known to grow successfully ; it is preferable to use a special culture because of the greater virulence of the cultivated bacteria.

During recent years a very great deal of research has been carried out upon the relationships of bacteria with milk and milk products. This work has revolutionized the production and handling of milk, and affects all consumers of the product. The real starting-point was the proof of the fact that a healthy cow produces milk which is free from bacteria. Milk is a substance secreted from groups of cells which form most of the tissues of the udder. These cells are amply supplied with blood from the milk " veins," and they discharge milk which collects in the ducts of the udder and in the milk cistern just above the teats. The teat is closed by a muscular ring, and if a sterile tube is inserted and some of the milk drawn off and examined, the milk is found to be sterile : no bacteria are present.

This is very significant, for it means that any germs in the milk as it reaches the consumer must have got in from outside sources. Of course an unhealthy cow may infect her milk, but the number of such cows is relatively very small because of modern methods of inspection and management. The problem of serving the public with pure milk is consequently a matter of paying special attention to methods of milking and handling.

Bacteria are almost everywhere. They are present in the air of cowsheds, on the hair of the cows, in the breath of man and beast; they can live in unclean utensils, they are carried on the feet of flies, and so on. A better realization of the possibilities of bacterial contamination has led to the adoption of improved methods of milking. Hair on the hindquarters and udders of cows is now clipped short. When this was first proposed objections were raised that it would adversely affect the health of the cows by giving them chills, but experience soon showed that this did not happen. The same objection was made when it was proposed to wash the flanks and udders of cows immediately before milking. Clipping and washing very greatly reduce the possibility of bacteria entering the milk in the cowshed, and the use of milk-pails with a domed or covered top in place of the enormously wide top of the ordinary bucket is a still further safeguard.

As an indication of what scientific inquiry may do in improving methods, one may quote the example of the milking-stool. Until quite recently this piece of equipment was regarded as nothing more than a necessity, and when not in actual use was allowed to kick about the cowshed or dairy in varying degrees of neglect and dirt. When the problem of clean milking methods was being seriously investigated it was realized that the milking-stool is a very possible source of contamination, as it is the last thing touched by a milker before he begins to milk. This has led to the treatment of the milking-stool as part of the equipment requiring special cleaning and sterilization, and the wooden article is giving way to stools made of more hygienic metal.

One of the most interesting pieces of research in dairying culminated in the discovery that dairy utensils, including churns, can be easily and rapidly sterilized over an ordinary farm copper or boiler. Most bacteria are killed in a very short time by temperatures above 80° C.

(176° F.), particularly if the heat is moist. Dairy utensils must, of course, be well washed to get rid of grease and dirt, but this washing, however well performed, does not rid the utensils of all bacteria. Scalding, which is the operation of swilling out vessels with boiling-hot water, is more efficient, but it obviously requires a lot of water and is a laborious and unpleasant process. Hoy found that by placing a lid over an ordinary copper full of boiling water, and allowing the steam to rise through a short tube about two inches in diameter, a very efficient steam sterilizer could be constructed at practically no expense. A 17-gallon churn placed upside-down over the "jet" becomes unbearably hot and is sterilized in a few minutes. Other utensils, such as the cooler, pails, dippers, and so on, can be sterilized in a wooden box placed over the "jet" for half an hour. This simple device is still being used on small farms, but the introduction of cheap steam sterilizing boilers and metal sterilizing cabinets has caused its supersession on larger farms.

The provision of ample supplies of steam is one of the most important items on a modern dairy farm, since it has been shown that for all ordinary purposes steam is the only satisfactory method of sterilization. The use of milking machines has made steam even more essential than before. Machine milking has an advantage over hand milking in that the vessels receiving the milk are entirely protected from dust during the actual process of milking. On the other hand, the machines are more complicated than buckets, and there are numerous teat cups and odd lengths of rubber and metal tubing to clean and sterilize. Without steam, these could not be properly freed from bacteria.

It may be asked, what is the object of taking such pains to keep bacteria out of milk when it is well known that many of the bacteria are quite harmless to persons consuming them? Apart from a natural desire to have as clean a product as possible, the numbers of bacteria in milk have a great influence upon keeping quality. Scientific tests show that the "going off" or souring of milk is almost entirely due to the numbers and types of bacteria present in it, and these numbers depend partly upon the initial contamination and partly upon the temperature at which the milk is stored.

It is almost impossible to destroy bacteria by exposure to even extreme cold, but at low temperatures bacteria develop slowly. For this reason the milk, which leaves the cow at body heat, is allowed to run slowly over a corrugated metal cooler or "refrigerator" within which is a circulation of cold water. This should lower the temperature of the milk to about five degrees above that of the water. The lower the temperature, the more slowly will the germs develop.

Particularly in summer it is impossible to maintain this low temperature during transit and distribution, and with rise in temperature there is an acceleration of the multiplication of bacteria. Before long, enough lactic acid would be formed to cause the milk to sour, or curdle, bringing about a dead loss, since such milk is unsaleable. The souring of milk, therefore, is seen to be a matter of initial contamination, temperature, and lapse of time between production and consumption.

Pasteurization offers a means of extending the keeping qualities of milk without seriously affecting its flavour, as well as destroying any disease germs that may be present. Pasteurization is a scientifically devised process whereby milk is exposed to a temperature of 145° F. (63° C.)

for thirty minutes, and is then cooled rapidly to 55° F. (13° C.). The high temperature kills off most of the bacteria, and the low temperature prevents the development of any that escape. Of course, pasteurized milk, if its temperature rises later on and it is exposed to further contamination, is just as liable to go sour as untreated milk, but there can be no doubt that its keeping qualities have been considerably improved. It is still a matter of controversy whether or not the feeding value of milk is seriously affected by the pasteurization process.

Some bacteria are a nuisance in the dairy, whilst others are essential to the production of butter and cheese. In the making of butter, for example, cream is separated from the liquid portion by a mechanical separator, and must be allowed to " ripen " before it can be churned. The ripening process is brought about by the development of lactic acid bacteria, which so affect the physical nature of the tiny fat globules in the cream that they cohere during churning. They also produce the desired flavour and aroma of the subsequent butter. The lactic acid bacteria form only a part of the bacterial population of milk, and it is quite possible for other forms to multiply and depress the lactic acid organisms. In such a case, ripening will not take place satisfactorily, and the amount and quality of the resultant butter are badly affected. To overcome this, and to ensure as far as possible a standard product, the practice of adding a " starter " to cream is widely adopted. A starter is a culture of virile lactic acid organisms; when added to the cream these organisms develop so fast that they crowd out any others that may be present, and so ensure that ripening shall proceed on correct lines.

Cheese, too, owes its flavour partly to the action of bacteria and partly to the action of moulds upon the proteins and other substances of which it is composed. Some of these organisms can live without oxygen, but others require air and perish if the supply fails. It sometimes happens that the interior of a cheese is deficient either in the organisms responsible for flavour, or in the air necessary for their growth. In such cases much good may be done by piercing the cheese with metal skewers, so that both organisms and air may enter. Frequently such holes become lined with a greenish material, which is often mistaken for verdigris. Actually the green colour is due to the presence of a mould, not to depositions from a copper wire as is so commonly supposed.

The researches of the dairy bacteriologist have made possible the introduction of "graded" milks, whose classification depends partly upon whether they have or have not come from tuberculin-tested cows, and partly upon their bacterial content. Tuberculin-tested cows are those which do not react (or show certain clinical symptoms) to injections of tuberculin, and which are therefore considered to be free from tuberculosis (see p. 128). Tuberculin-tested milk and Tuberculin-tested milk (Pasteurized) are the highest grades. Accredited milk and Pasteurized milk are the other grades.

Until very recently the numbers of bacteria in milk were estimated by the plate method, in which dilutions of milk are mixed up with a jelly in shallow glass dishes and placed in incubators. Any bacteria present multiply rapidly, each single bacterium giving rise to descendants so numerous as to form a visible speck, or colony. By counting the colonies and multiplying by the dilution, an estimate of the bacteria present in one cubic centimetre of the original milk can be obtained.

This method proved to be tedious and time wasting, and, although it is more precise, it has now been largely superseded for routine examinations by the "Reductase" test.

This method depends upon the fact that the bacteria in milk, in conjunction with certain "reducing" substances also present, will decolorize a dye known as methylene blue. The larger the bacterial population, the more rapidly does the dye lose its colour. By watching the rate at which decolorization proceeds it is possible to estimate fairly accurately the numbers of bacteria present in a sample of milk. Since the methylene blue reductase test takes only from 5 to 6 hours as opposed to the 48 hours required by the plate method, more testing can be carried out in a given time by an operator.

The test is carried out by putting standard quantities of milk and methylene blue into narrow glass tubes six inches long, and standing them in the dark in a water bath kept at 37° C. They are examined every half-hour. The standards for Tuberculin-Tested (Certified) milk and Accredited milk are that the methylene blue must not be decolorized within 4½ or 5½ hours according to the time of year.

Pasteurized milk cannot be examined by the reductase test because heating destroys the reducing substances in it. The plate method is therefore still used. Tuberculin-Tested (Pasteurized) milk must not contain more than 30,000 bacteria per cubic centimetre (or millilitre), and ordinary Pasteurized milk not more than 100,000 bacteria per cubic centimetre.

COLLATERAL READING

The behaviour of soil bacteria is explained in *Soil Conditions and Plant Growth*, by Sir E. J. Russell (Longmans, Green & Co., 1937). To understand more fully the influence of modern bacteriological work upon the milk industry, consult *The Handling of Milk and Milk Products* (Bulletin 31 of the Ministry of Agriculture, 1937) and *Bacteria in relation to the Milk Supply*, by C. H. Chalmers (Edward Arnold, 1935).

CHAPTER X

THE WORK OF THE ENGINEER

The development of the internal combustion engine has had a greater influence upon farming than any other single factor during the last thirty years. Farming is very largely a matter of applying power to the land or to operations in and around buildings. On purely grass farms very little power is required, but on large mixed farms a great deal is necessary. Man-power, oxen-power, and horse-power have been used for thousands of years, and with the invention of the wheel it became possible to utilize the wind and water as sources of energy. Until the invention of the steam engine about two hundred years ago there were no other sources of power, and steam engines were so costly and cumbersome, and their radius of effective action so small, that very few farms were able to utilize the power of steam.

Of course steam exercised an influence on agriculture as it did upon all sections of national life. Improvements in communication, which began with the canal era, were continued by the railways, and this meant larger markets ; incidentally it opened up native farming to competition from the whole world. Laborious operations like threshing, previously carried out by teams of men and women, could be performed by peripatetic steam threshing tackle. Ploughing on really stiff land was accelerated by steam ploughs, and so on. But steam was not available where and when it was wanted on the farm, and so exercised chiefly an indirect influence.

The oil motor, however, has made it possible to take power to almost any part of the farm. It has not only made it possible to perform certain stationary tasks, such as pumping, grinding, and sawing, very much more rapidly, thus taking much of the drudgery out of farm work, but it has also had a considerable influence upon the cultivation of the soil and the harvesting of crops.

To the average townsman the oil engine in agriculture is associated with the farm tractor, but the latter is at the moment possibly of minor importance compared with the portable stationary engine. There is scarcely a farm which does not use a fixed oil engine of some sort, whilst tractors are by no means universally employed. Most of the farms in this country are small, less than a hundred acres in extent, and whereas a stationary engine can be bought for less than £10, a tractor costs at least £100.

On the other hand, there is an increasing tendency for the tractor to become a general purpose machine. The early tractors, hurriedly developed during the war, were heavy, cumbersome things which could do little more than pull implements of cultivation such as ploughs and cultivators. The modern tractor is smaller, lighter, and altogether more nimble, developing more power, more efficiently, and more economically. Equipped with the new pneumatic rubber tyres, it can be used for cultivating the land and for general hauling purposes; and by virtue of its manœuvrability it is able to perform many of the jobs for which stationary engines are employed.

The reduction in size and weight of tractors has also made their use possible for what is termed " row-crop " work. The cultivation of the soil between rows of turnips or lucerne, for example, can now be carried out by tractors, and the use of these machines in market gardening is extending.

One of the great advantages of tractor power over horse labour is the ability of the machine to do a job quickly at the proper time. Weather plays such an important part in farming operations that the speed of the tractor is most valuable in taking advantage of favourable conditions. In this respect it has a great advantage over horse labour, especially on large farms. Tractors, too, are sometimes able to tackle jobs that horses cannot successfully accomplish. An example is the cultivation of poor hill grazings at high altitudes in parts of Wales under the Kahn Hill Improvement Scheme. Here large track-laying tractors are used in preference to the usual wheeled type, as they are more controllable on steep slopes.

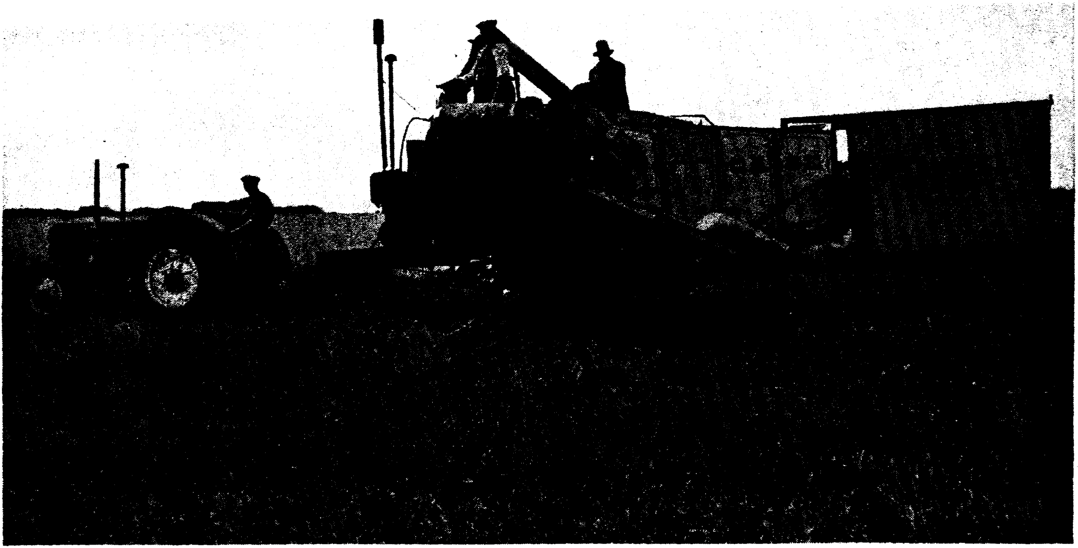
Much of the farm land of this country is cut up into small fields, so that the ability of the tractor, especially the larger ones, to haul several implements of cultivation at once is really not very important. On mechanized farms with few hedges and ditches it is possible to seed, harrow, and roll in one operation. This, of course, means additional outlay on implements.

The tractor is very suited to harvesting operations on both large and small farms. The mowing of hay and cutting of cereals are operations which are hard on horses. The modern tendency is to devise mowing and reaping machines whose working parts are driven direct from the tractor instead of from the land wheels. Neither mowers nor " self binders " have undergone any radical alteration during the last quarter of a century, but the development of the power take-off direct from the tractor leads to more efficient operation and reduced draught.

One striking introduction of the last few years is the combine-harvester, which is employed on grain producing farms of a large size. The combine is a piece of machinery hauled by a tractor, but provided with its own oil engine to drive its internal workings. The smaller combines are driven by a power take-off from the tractor. The first used in this country was demonstrated in 1928. The combine cuts swaths up to twelve feet wide of a dead ripe cereal crop, threshes out the grain and deposits it in bins or in bags, and throws out the straw. A lorry drawn by a tractor can run alongside the combine and receive the threshed grain without interfering with the harvesting operation. Naturally, this method of grain harvesting is very rapid. It takes the fullest advantage of spells of fine weather, saves expenditure on binder twine, and does away with the expense of stacking and the losses that take place in the stack, and eliminates separate threshing charges.

The combine is, of course, a relatively expensive implement, and in addition, owing to the humidity of our climate, it is usually necessary to install a drier to dry the grain artificially after it leaves the combine. Wheat, as harvested, may contain up to 30 per cent. of moisture, and before it can be safely stored it is essential that the moisture content be reduced to between 14 and 16 per cent. To effect this the grain is exposed in thin layers to a draught of hot air at a temperature not exceeding 150° F., sucked or blown through the drier, which may be either of the vertical or horizontal type.

The straw left by the combine is either stacked in the



Combine-harvester drawn by a pneumatically tyred tractor.

The combine itself is operated by the oil engine mounted over the front wheel. Corn is cut and threshed in one operation, the grain being discharged in bags at the rate of 40 four-bushel sacks per hour.

(*By permission of Associated Manufacturers Co., Ltd.*)

loose state or swept up and made up into bales by a baling machine. Machines which pick up and bale the straw as it goes along are also used. Balers are becoming increasingly popular wherever hay and straw have to be dealt with, because baled fodder is more easily stored and handled, and there is less waste. The baler is essentially a machine for compressing the fodder and securing it in a rectangular mass with twine or wire. The cost of baling is small considered in relation to its advantages. Hay has even been baled straight from the field.

The oil engine is doing a great deal to speed up the hay harvest, which on very many farms is much more important than the grain harvest. Mention has already been made of the mower with direct power-drive from the tractor. Stacking has been made simpler by using hay-sweeps attached to the front of tractors or old, high-powered cars. Cars fitted out in this way can collect hay from all parts of the field at speeds of up to twenty miles an hour, and bring it in loads of several hundredweights direct to the base of the stack, eliminating the pitchforking process and the horse-drawn wagon. The hay is either thrown up to the stack in heaps by means of a hay-fork operated by the tractor, or carried up on an elevator worked by a small stationary engine.

The most interesting recent development in scientific farming made possible by engineering methods is that of grass drying. About 1925 Woodman at Cambridge carried out a number of analyses of young, growing grass approximately four to six inches long, and made the surprising discovery that it is very rich in protein. So rich is young grass in nutritive constituents that it can be looked upon as similar to a protein concentrate such as linseed cake. The proportion of carotene in young grass is also high, and this is a valuable point, because carotene is the precursor of vitamin A, one of the most important of the accessory food factors. It was also found that young grass, quickly dried, retains practically all its nutriment, and is very palatable. The interesting speculation then arose: Is it possible on a farm scale economically to cut, dry, and store young grass for winter use?

The advantages of being able to do this are, theoretically at least, very great, both from an individual and a national point of view. At present, most of the concentrated feeding stuffs used on the farm have to be imported from Empire and foreign sources; they do not contain any considerable amounts of vitamins, and they are expensive. If British farmers could make their own concentrates for winter use it would save them money, cut down imports, and be at the same time a national insurance against scarcity in times of war. The health of our dairy herds in winter and the quality of their products might also be improved by the extra vitamins.

After several years of experiment a grass-drying plant was put on the market in 1936, and since then others have been designed and operated on farms in all parts of the country. The problem in all grass driers is to cut down the percentage of water from approximately 85 per cent. to about 6 per cent. in the shortest possible time without scorching or otherwise injuring the grass. In the early models, hot air from a coke furnace was drawn over thin layers of grass set out on trays, an electric fan being used for the purpose. When dry, the grass is pressed into bales by a hydraulic press and stored away from light, which reduces the carotene content. In another type of drier the grass is exposed to hot air whilst passing through a chamber on a continuously moving belt; yet another has a revolving drum heated by oil burners. Mobile driers are also obtainable, which can be taken from one part of the farm to another, so as to be close to the source of grass.

The future of grass drying lies chiefly with the engineers, though chemical and botanical aspects also need investigation. The scientific facts underlying the process are sound enough, but at present the process is too costly to appeal to many farmers. The rate of evaporation of water is as yet much too slow, and the output of most driers is only about two hundredweights of dried grass per hour. This is understandable, because the engineers have not yet had time to experiment and test out under farm conditions their schemes for taking water out of grass. After all, the tractor has had nearly a quarter of a century of intensive research spent upon it to bring it to its present pitch, and this ought to be remembered when discussing the failings of existing driers, which are admittedly experimental. As so often happens in farming, a new suggestion is often killed by the misguided and mistimed enthusiasm of its supporters. Grass drying is at the moment suffering because it has not yet been able to fulfil the extravagant claims made for it when the idea was first mooted, but it is one of the most pregnant conceptions in modern scientific agriculture.

The foliage of lucerne is also being dried at one centre in England. It is cut, dried, pulverized, and bagged within from two to four hours, with the result that its vitamin content suffers no reduction. The meal commands a ready sale for inclusion in compound rations, particularly those used in winter.

Cheap power, made available by the use of oil engines and electricity, has brought about many changes in the production and handling of milk on the farm. The spread of milking machines has been rapid during recent years. When first introduced at the end of last century milking machines were found to be unreliable, and they suffered a temporary eclipse and fell into considerable disfavour. Recent developments, including the better design of the teat cups, improved vacuum or suction, the extended use of stainless metals, the increased use of electric motors in place of oil engines, and all round greater reliability have restored milking machines to favour. Some types not only milk the cows, but automatically record the weight of milk at the same time. Hand milking is hard and monotonous work. Electric light and milking machines have done much to make milk production less arduous.

Electrically operated cold storage rooms and cream separators are also being used to a greater and greater extent. The dairy is a place where electricity has a great advantage over the oil engine owing to its cleanliness.

One interesting innovation of recent years is the portable milk bail, or open-air milking outfit. This is a wooden shed on wheels capable of accommodating several cows at a time. It is accompanied by another house on wheels containing an oil engine and a milking machine. The complete outfit is taken by a tractor to the fields in which the cows are out at grass, and milking is performed in the open air. There are no overhead costs in the shape of expensive cowhouses where this method is adopted, and by keeping the animals always in the open certain diseases are avoided; in addition, the pastures may be much improved, since the manure is

A grass-drying plant.

Grass is dried in the trays on the right, which are pushed into the hot-air chamber behind. On the left is the hydraulic baling press, and in the foreground are bales of dry grass.

returned direct to the land. Naturally this system needs a not too extreme winter climate.

The use of electricity has already been referred to in connection with the dairy. Another ingenious use of current is now being made by poultry keepers to encourage hens to lay more eggs in winter when prices are high. By means of a time-switch, poultry laying-houses are illuminated after dark for an hour or two to encourage more scratching and to discourage the normal roosting which takes place when the sun has set. It is found that this extra exercise results in more eggs per bird, whose value is much greater than the extra cost of the illumination.

Turning now to the actual implements used on the farm, it may be said that modern engineering progress is being reflected in the manufacture of lighter articles. The change over from wrought iron to steel makes it possible to obtain equal strength for less weight, and this means, as a rule, less work for horses and tractors. There have been no basic changes in the design of ploughs, cultivators, harrows, and rollers during recent years, though, of course, detailed improvements are continually being made. Increased attention is being directed to accuracy of distribution in seed drills and manure drills, whose performance is not all that can be desired. The introduction of machines that will transplant such things as young cabbages shows that ingenious brains are being turned to problems of agricultural engineering.

A development that must have been observed by all who move about the country is the use of pneumatic tyres both on tractors and farm carts. Tractors with pneumatics are much more "general purpose" than those with iron wheels, for the strakes, or spuds, on the latter, which are necessary to prevent wheel-spin on cultivated land, have to be removed or covered before the tractor can be used on the road. Properly designed pneumatic tyres of large size do not slip except on very bad surfaces, and they add immensely to mobility. Farm carts on pneumatic tyres are much appreciated by workmen. Usually the wheels are on roller bearings instead of plain bearings, and the combination leads to a considerable reduction in draught, which enables a horse to pull more, especially on soft ground. Pneumatically tyred wheels can also be much smaller in diameter than ordinary wooden wheels with iron rims; this means a lower centre of gravity, and a lower loading position.

One interesting problem that the engineer will have to solve is that of "rotary" cultivation. Traditional methods of preparing a seed bed involve three or more separate operations in which the soil is moved from side to side. Ploughing, harrowing, and rolling are necessary to break down the soil into a fine state. Is it justifiable to use a tractor on these implements, designed for slow moving oxen or horses? Why not make a tilth in one operation by an implement having rotating teeth? There are such implements in use doing satisfactory work on market garden soils and on grass land, but their use on the general farm has not been extensive. The problem is a controversial one.

COLLATERAL READING

Developments in agricultural engineering can best be studied in the agricultural press, reports issued by the Agricultural Engineering

Institute, University of Oxford, or in the annual survey set out in the Journal of the Royal Agricultural Society. The *Implement and Machinery Review* is a monthly journal devoted to the subject. The present position of grass drying is summarized by E. J. Roberts in *Grass Drying* (H.M. Stationery Office, 1937).

CHAPTER XI

SCIENCE AND THE CONTROL OF AGRICULTURE

A MODERN state is a very complicated affair in which discipline is essential to a harmonious existence. The personnel of a great industry like agriculture have to submit not only to the general discipline of the community, but also to restrictions upon individual liberty made necessary by the needs of the industry itself. Some of these restrictions have been shown to be necessary as the result of scientific investigations in various problems, whilst others are more matters of political expediency.

The Seeds Act, 1920, is an example of a piece of legislation based upon scientific evidence. Under the provisions of this Act, the vendor of almost all agricultural seeds is compelled to guarantee the quality of his wares. The farmer requires information upon three main points before purchasing seeds, namely, the kind of seed, its freedom from impurities, and its germination. The Seeds Act requires that this information be given to a prospective purchaser, and it backs up its requirements by the scientific analysis of seed samples.

The history of the seed trade shows that from time to time the adulteration of seeds has caused considerable losses to farmers. Generally speaking, farmers are not well acquainted with the different kinds of seed they have to handle, and to substitute one kind for another would be a simple matter. The substitution of charlock seed for turnip seed was, in fact, practised at one time—the weed seed being first killed by baking in an oven to prevent the young plants from disclosing the fraud. This sort of thing is no longer done, because seed analysts can discover the adulteration at once. Analysis can in many cases also determine if a sample of seed is home grown, or comes from a foreign country—the nature of the weed seeds present in the sample makes this possible. This may be an important point, because some foreign clovers have a good-looking seed, but are actually very inferior as crop plants. The determination of the percentage of purity and the percentage germination are obviously precise scientific tests, and because the trade in seeds is world wide, the technique of the tests is a matter for international discussion. The point is that, without scientific backing, it would be impossible to carry out regulations designed to provide the farmer with reliable seeds.

In a similar way the operation of the Fertilizers and Feeding Stuffs Act, 1926, depends fundamentally upon the findings of the scientist. This Act aims at compelling the makers of manures and feeding stuffs used bv the farmer to guarantee their quality, and in short it insists upon the vendor stating the chemical composition of his products. This can be found out only by careful and systematic analysis conducted in a standard manner. This Act is by no means entirely satisfactory, because the onus of starting legal proceedings in a case of suspected discrepancy or fraud is laid upon the farmer himself. In the case of the Seeds Act, government officials are continually taking check samples to ensure that misleading or false declarations are not being made. No such check samples are taken in the case of fertilizers and feeding stuffs; the farmer has to suspect and to ask for samples to be taken before authority will move. In this respect the Act can scarcely be called scientifically designed.

An Act of a very different sort, though based again on scientific evidence, is the Destructive Insects and Pests Act (1887–1927). Its purpose is to keep out of this country certain insects and fungus pests which in other countries cause great losses to farmers. To show how very important this Act may be, we have only to consider the Colorado Beetle. This beetle has long been known as a serious pest of potatoes in the United States of America and in Canada. The beetle itself is shaped rather like a large Ladybird beetle, with alternating stripes of black and yellow running along its back. Both the adult insect and its larva devour the leaves and stems of potatoes, and, if unchecked, may cause serious losses. In areas where the beetle is active, farmers have to spray their potato crops with poisonous substances containing arsenic—an expensive proceeding. The American Expeditionary Force brought the Colorado Beetle to France in 1919, and the insect soon spread over almost all the potato growing districts in that country, and then invaded Belgium, Luxembourg, and parts of West Germany. The importation of potatoes into this country is prohibited if the Colorado Beetle has been known to exist within fifty kilometres of their place of cultivation. In a similar way the importation of Elm plants, sugar beet plants, and cherries, amongst others, is forbidden, except in special circumstances, so as to prevent the introduction of pests attacking these species.

At the same time farmers and growers in this country must notify the proper authorities, usually the police or the Ministry of Agriculture, if certain pests and diseases make an appearance in their property. Reference has already been made (p. 114) to the regulations designed to prevent the spread of Wart disease in potatoes, which is the most important fungus disease subject to legislation. In attacking insect and fungus enemies speed is essential, and this makes compulsory early notification very desirable.

A number of diseases of animals is also notifiable under the various Diseases of Animals Acts. Wide powers are given to the Ministry of Agriculture's inspectors under these Acts in dealing, for example, with foot-and-mouth disease in cattle, sheep, pigs, and deer. Slaughter and burning of infected animals and those coming in contact with them, isolation, and disinfection of premises are the immediate consequences of an outbreak of foot-and-mouth disease in this country. The procedure for dealing with swine fever in pigs is also quite drastic. Sheep scab, caused by parasitic mites, is also subject to a number of regulations, and double-dipping of infected and contact animals becomes compulsory. Warble fly in cattle is one of the most recent pests to be attacked by legislative enactments. Other diseases which on account of their infectious or contagious nature require the immediate application of scientific control methods include anthrax and fowl pest.

Control of agriculture in a much wider fashion is being applied as the result of other investigations, notably in economics. Economics cannot be considered an exact science, because the studies with which it is concerned deal with the reactions of human beings, which are less reliable than the working of so-called natural laws. Political considerations are always liable to bring about a reorientation of outlook on problems of economics; it must be admitted also that the opinions of individuals, unsupported by incontrovertible hard facts, can assume an importance in this branch of study which they could never attain in one of the more precise sciences. Nevertheless, economics is much more than a mere criticism of the effects of science and politics on life, which is the point of view of some people.

Economics is based largely upon a study of both history and figures. No study can be called a science until it can offer some sort of measurement to provide a basis from which to begin, and from which a comparison of effects can be made. Inasmuch as economics is primarily concerned with a consideration of figures and measurements, it must be looked upon as a science. Science is systematic observation, combined with deduction from established facts. Economics is not an exact science, because the established facts are very liable to variation owing to changes in habits and points of view.

Actually, the conclusions of economists are liable to bring about much more sudden changes in the industry of agriculture than the investigations of scientists. Take the case of the sugar beet industry, which is now a very widespread one, employing thousands of land workers, factory workers, technicians, plant breeders, and so on. It was the botanists and the chemists who raised the proportion of sugar in the beet root from about 4 per cent. to 20 per cent. (see pp. 51–54), but it was the suggestion of economists that made the crop possible in this and other countries. Despite all the efforts of applied scientists, the sugar beet plant is still much inferior to the sugar cane as a source of cheap sugar. Political considerations, not the intrinsic worth of the beet plant, brought about the development of this new crop. Unassisted, sugar beet could never have established itself in competition with the sugar cane, but by a system ot subsidies it has been fostered in order to help maintain the fertility and prosperity of the countryside.

The scientific study of marketing is playing a great part in helping to maintain yet another important crop, potatoes, hitherto very much at the mercy of fluctuating conditions. A Potato Marketing Scheme for Great Britain came into being in 1934 and is administered by an elected Board. All potato growers (and there are more than 66,000) have to be registered, and the acreage under the crop is limited, a penalty being exacted for excess acreage planted. The Board regulates the market by prescribing minimum-sized riddles over which potatoes sold for consumption must be dressed. An increase in the size of the riddle, or sieve, over which the tubers have to be passed keeps the smaller potatoes off the market, and so reduces market supplies and maintains the price. The Board also has a voice in the matter of imports of potatoes from abroad.

There is also a Milk Marketing Scheme, which began in 1933. Scientific methods of milk production, amongst which may be mentioned food rationing (p. 94) and the extended use of machinery (p. 164), led to such a tremendous increase in liquid milk supplies, followed by such intense cut-throat competition, that a catastrophic fall in prices took place during 1931–32. The study of hundreds of farm accounts showed the unremunerative nature of dairy farming, and to improve matters the Milk Marketing Scheme was devised. The principle of the scheme is that all milk must be sold through a Board. The Board charges different prices according to the uses to which the milk is put; some of it is sold for liquid consumption, some for manufacturing purposes such as the making of butter and cheese, the production of milk powders, the manufacture of casein, and so on. Farmers who retail their own milk have to pay a levy to the Board, and there is a complicated arrangement for the pooling of returns from the eleven regions into which the country has been divided. Each farmer receives his payment monthly from the Board. One interesting feature of this scheme is that the necessary calculations are so involved that it could not be worked without the assistance of the mechanical calculators which science has made possible.

Incidentally, it may be said that actual production of milk is subject to many different regulations. Milk is so important an article of food and so liable to damage that a number of precautions is insisted upon by the Government in the Milk and Dairies Order (1926). These precautions are all founded upon the results of scientific research. They include the detection and treatment of disease in the cows themselves, and in the milkers, and the production of and maintenance of clean conditions in cowsheds, dairies, and utensils.

COLLATERAL READING

A good idea of the complicated regulations affecting agriculture can be obtained from a study of the *National Farmers' Union Year Book*. The *Agricultural Register*, published annually by the Agricultural Economics Research Institute at Oxford, is the most useful general record of legislation, organization, supplies, and prices. Regulations and Orders affecting farming are published in the *Journal of the Ministry of Agriculture*, and an annual summary of developments in economics is given in the Journal of the Royal Agricultural Society.

CHAPTER XII

AGRICULTURAL EDUCATION AND RESEARCH

THE scheme for agricultural education and research in England and Wales is a complicated one, and is administered partly by the Ministry of Agriculture, partly by County Councils, partly by universities, and to a less extent by private foundations. The technical instruction of intending farmers and those desiring official and commercial appointments is carried out in University Departments of Agriculture and at Agricultural Colleges, whilst training of a less specialized nature is given at Agricultural Institutes. Research into agricultural problems is conducted at specialized Research Institutes, whilst many of the teaching staffs at universities and colleges also carry out investigations in which they are particularly interested.

The County Councils employ trained men to advise farmers on their problems within their own country areas ; these are called Agricultural Organizers, and with their staffs they conduct experimental work, demonstrations, and courses of education.

To assist the educational work in the counties, the country has been divided up into thirteen areas, each served by a Provincial Advisory Centre, usually a university or college. At each centre is stationed a number of specialist Advisory Officers in Chemistry, Plant Diseases, Insect Pests, Veterinary Science, Dairy Bacteriology, and Economics. These advisory officers deal with inquiries which need specialist knowledge, and also conduct research into local problems.

The Advisory Centres, together with the Provinces they serve, are as follows :

1. *King's College, Newcastle-on-Tyne :* Cumberland, Durham, Northumberland, and Westmorland.
2. *University of Leeds :* Yorkshire.
3. *Midland Agricultural College, Sutton Bonington, near Loughborough :* Derbyshire, Leicestershire, Nottinghamshire, Rutland, Kesteven Division of Lincolnshire.
4. *University of Cambridge School of Agriculture :* Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Huntingdonshire, Norfolk, Suffolk.
5. *South-eastern Agricultural College, Wye, Kent :* Kent, Surrey, Sussex.
6. *University of Reading :* Berkshire, Buckinghamshire, Dorset, Hampshire, Middlesex, Northamptonshire, Oxfordshire.
7. *Seale Hayne Agricultural College, Newton Abbot, Devonshire :* Cornwall, Devon.
8. *University of Bristol :* Gloucestershire, Herefordshire, Somersetshire, Wiltshire, Worcestershire.
9. *Harper Adams Agricultural College, Newport, Shropshire :* Shropshire, Staffordshire, Warwickshire.
10. *University of Manchester :* Cheshire, Lancashire.
11. *University College of North Wales, Bangor :* Anglesey, Carnarvonshire, Denbighshire, Flintshire.
12. *University College of Wales, Aberystwith :* Brecknockshire, Cardiganshire, Carmarthenshire, Merionethshire, Montgomeryshire, Pembrokeshire.

Aspects of scientific training at an agricultural college.

Above.—Making precision records on a growing crop.

Below.—Students at work in a botanical garden.

(*By permission of Harper Adams Agricultural College.*)

13. *University College of South Wales, Cardiff:* Glamorganshire, Monmouthshire.

In addition to the Universities and Colleges mentioned in the list of advisory centres, educational facilities for those desiring to take a degree or diploma are available at the Royal Agricultural College, Cirencester.

Instruction of a less advanced type is provided at the County Farm Institutes, which are as follows :

Cheshire : *School of Agriculture, Reaseheath, Nantwich.*

Cumberland and Westmorland : *Newton Rigg Farm School, Penrith.*

Essex : *East Anglian Institute of Agriculture, Chelmsford.*

Hampshire : *Farm Institute, Sparsholt, Winchester.*

Hertfordshire : *Agricultural Institute, Oaklands, St. Albans.*

Kent : *Borden Farm Institute, near Sittingbourne.*

Lancashire : *County Council Farm School, Hutton, Preston ; and Harris Institute, Preston.*

Lincolnshire (Holland Division) : *Agricultural Institute, Kirton, Boston.*

Northamptonshire : *Institute of Agriculture, Moulton, Northampton.*

Somersetshire : *Somerset Farm Institute, Cannington, Bridgwater.*

Staffordshire : *Rodbaston Farm Institute, Penkridge, Stafford.*

Suffolk : *Chadacre Agricultural Institute, Hartest, Bury St. Edmunds.*

Sussex, East : *Sussex School of Agriculture, Plumpton.*

WALES

Carnarvonshire: *Madryn Castle Farm School, Bodfean.*

Carmarthenshire: *Pibwrlwd Farm Institute, Carmarthen.*

Denbighshire: *Llysfasi Farm Institute, Ruthin.*

Monmouthshire: *Institute of Agriculture, Usk.*

The Research Institutes, together with their subjects of research, are:

Animal Nutrition: *Animal Nutrition Research Institute, School of Agriculture, Cambridge.*

Animal Pathology (Diseases): *Institute of Animal Pathology, Cambridge; Ministry of Agriculture Veterinary Laboratory, New Haw, Weybridge, Surrey; Royal Veterinary College, Camden Town, London, N.W.1.*

Botany: *Royal Botanic Gardens, Kew.*

Crop Testing; Development of new varieties of crops; Seed Testing; Potato Testing: *National Institute of Agricultural Botany, Huntingdon Road, Cambridge.*

Dairying: *National Institute for Research in Dairying, Shinfield, near Reading.*

Economics: *Agricultural Economics Research Institute, Parks Road, Oxford.*

Engineering: *Institute of Agricultural Engineering, Parks Road, Oxford.*

Fruit Culture: *Agricultural and Horticultural Research Station, Long Ashton, Bristol; Fruit and Vegetables Preserving Station (Bristol University), Campden, Glos; East Malling Research Station, East Malling, Kent.*

Parasitology: *Institute of Agricultural Parasitology,* *London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1.*

Plant Breeding (Horticultural Crops): *John Innes Horticultural Institution, Merton Park, S.W.19.*

Plant Breeding (Cereals): *Plant Breeding Research Institute, School of Agriculture, Cambridge.*

Plant Breeding (Grasses and Forage Crops): *Welsh Plant Breeding Station, Agricultural Buildings, Alexandra Road, Aberystwith.*

Plant Pathology: *Ministry of Agriculture Pathological Laboratory, Harpenden, Herts; Rothamsted Experimental Station, Harpenden, Herts.*

Plant Physiology: *Institute for Research in Plant Physiology, Imperial College, South Kensington, S.W.7.*

Poultry Husbandry: *National Institute of Poultry Husbandry, Harper Adams Agricultural College, Newport, Shropshire.*

Small Animal Breeding: *Small Animal Breeding Research Institute, School of Agriculture, Cambridge.*

Soils and Plant Nutrition: *Rothamsted Experimental Station, Harpenden, Herts.*

Vegetables: *Horticultural Research Station, School of Agriculture, Cambridge.*

Vegetable and Glass-house Crops: *Experimental and Research Station, Cheshunt, Herts.*

Since 1929 a number of Imperial Agricultural Bureaux has been established "to collect, collate, and disseminate information in selected branches of agricultural science, and generally to assist research workers in the Empire on their subject." Each bureau deals with one of the following branches of agricultural science and is located at an institute already well known for research in its branch:

Soil Science : *Rothamsted Experimental Station, Harpenden, Herts.*

Animal Nutrition : *The Reid Library, Rowett Institute, Bucksburn, Aberdeen.*

Animal Health : *Veterinary Laboratory, New Haw, Weybridge, Surrey.*

Plant Genetics (crops other than Herbage) : *School of Agriculture, Cambridge.*

Plant Genetics (Herbage) : *Agricultural Buildings, Alexandra Road, Aberystwith.*

Fruit Production : *East Malling Research Station, East Malling, Kent.*

Animal Genetics : *King's Buildings, University of Edinburgh.*

Agricultural Parasitology : *Winches Farm, Hatfield Road, St. Albans, Herts.*

Dairy Science : *National Institute for Research in Dairying, Shinfield, near Reading.*

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